ROLE OF INGREDIENT COMBINATION ON BUTTER CAKE QUALITIES

BY

MS. SUWORANEE PANCHAROEN

A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY (FOOD SCIENCE AND TECHNOLOGY)
DEPARTMENT OF FOOD SCIENCE AND TECHNOLOGY
FACULTY OF SCIENCE AND TECHNOLOGY
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FACULTY OF SCIENCE AND TECHNOLOGY

DISSERTATION

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MS. SUWORANEE PANCHAROEN

ENTITLED

ROLE OF INGREDIENT COMBINATION ON BUTTER CAKE QUALITIES

was approved as partial fulfillment of the requirements for
the degree of Doctor of Philosophy in Food Science and Technology

on August 3, 2017

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ABSTRACT

This research aimed to cluster commercial sliced cakes by its texture properties and studied the effects of the ratio of main ingredients combination on their texture properties in order to cluster with commercial cakes. From Cluster analysis using Hierarchical model with principal component analysis (PCA) of texture profile analysis (TPA) values of commercial cake (12 products) used together with butter cakes obtained by varying the ratio of 4 ingredients including sugar, butter, margarine and egg, experiments were designed by central composite design (CCD) of 27 treatments, could be divided into 4 groups. Cake group I (low ratio of sugar, high ratio of butter, margarine and egg, $S_LB_HM_HE_H$), which had texture properties of low springiness, cohesiveness, gumminess and chewiness. Cake group II (low ratio of sugar and egg, high ratio of butter and margarine, $S_LB_HM_HE_L$) which had texture properties of low springiness, cohesiveness and resilience but high in gumminess. Cake group III (low ratio of sugar and butter, high ratio of margarine and egg, $S_LB_LM_HE_H$) which had texture properties of high in springiness, cohesiveness, gumminess and chewiness but low in resilience. And cake group IV (low ratio of sugar, butter, margarine and egg, $S_LB_LM_LE_L$) which had texture properties of high springiness, cohesiveness and resilience. The result of studying the effect of the ratio of main ingredients combination on texture properties of batter cake (27 treatments) was expressed by using response surface methodology (RSM) and creating regression equation of full quadratic model. It was found that the regression equation could explain the best relationship of the main ingredients on springiness and cohesiveness (R^2=0.95 and 0.94 respectively). Since the interaction between butter and margarine was significant different on springiness, the contour plot of both ingredients on the springiness revealed that low level of them led to high springiness of cake. Moreover, sugar and butter as well as sugar and egg had interaction on cohesiveness. Low level of sugar and butter as well as high level of sugar and egg caused high cohesiveness of cake. The correlation between the groups of cake, microstructure, texture properties and sensory properties using Quantitative descriptive analysis (QDA) and a line intensity of 15 scale, was analyzed by using PCA, found that $S_LB_HM_HE_H$ had high number of air cells per unit area, high in the intensity of color and pore size but low in the intensity of hardness and cohesiveness, and low in hardness, springiness, cohesiveness, gumminess, chewiness and resilience. $S_LB_HM_HE_L$ had high mean cell area but low in number of air cells per unit area, high in the intensity of color and hardness but low in the intensity of pore size and cohesiveness, and high in hardness, gumminess and chewiness but low in cohesiveness, springiness and resilience. $S_LB_LM_HE_H$ and $S_LB_LM_LE_L$ had low mean cell area but high in number of air cells per unit area, low in the intensity of color but high in the intensity of hardness, pore size and cohesiveness, and high in hardness, gumminess, chewiness, cohesiveness, springiness and resilience. However $S_LB_LM_HE_H$ was higher in resilience than $S_LB_LM_LE_L$. All cake groups could keep at 25°C for 6 days or 4°C for 18 days without spoilage of total bacteria, yeast and mold, *Stapphylococcus aureus* and *Bacillus cereus.* The values of hardness, gumminess and chewiness of cakes for each group at 25°C and 4°C were increased but springiness, cohesiveness and resilience of cakes for each group decreased with storage time. The retrogradation rate and enthalpy of cakes from each group stored at both 25°C and 4°C were increased, whereas the sensory properties were decreased with storage time.

Keywords: butter cake, microstructure, butter, sugar, margarine, egg

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บทคัดย่อ

งานวิจัยนี้มีวัตถุประสงค์เพื่อจัดกลุ่มเค้กเนยแบบสไลด์ที่มีจำหน่ายในเชิงพาณิชย์ตามลักษณะเนื้อสัมผัสและศึกษาผลของอัตราส่วนของส่วนผสมหลักต่อลักษณะเนื้อสัมผัสของเค้กเนยเพื่อจัดกลุ่มร่วมกับเค้กเนยที่มีจำหน่ายเชิงพาณิชย์ (12 ผลิตภัณฑ์) จากการวิเคราะห์การจัดกลุ่มด้วยวิธีคลัสเตอร์แบบ Hierarchical ร่วมกับเทคนิคการวิเคราะห์องค์ประกอบ (Principle component analysis; PCA) ต่อลักษณะเนื้อสัมผัสของเค้กเนยที่มีจำหน่ายในเชิงพาณิชย์และเค้กเนยที่ได้จากการแปรอัตราส่วนของส่วนผสม 4 ชนิด คือ น้ำตาล เนย มาร์การีน และไข่ โดยวางแผนการทดลองแบบ Central composite design (CCD) จำนวน 27 สิ่งทดลอง สามารถจัดกลุ่มเค้กเนยได้ 4 กลุ่ม คือ (I) เค้กที่ใช้อัตราส่วนของน้ำตาลต่ำ แต่อัตราส่วนของเนย มาร์การีนและไข่สูง ($S_LB_HM_HE_H$) เป็นเค้กที่มีความยืดหยุ่น ความสามารถในการเกาะรวมตัว ความเหนียวคล้ายยางและความยากในการเคี้ยวต่ำ (II) เค้กที่ใช้อัตราส่วนของน้ำตาลและไข่ต่ำ แต่อัตราส่วนของเนยและมาร์การีนสูง ($S_LB_HM_HE_L$) เป็นเค้กที่มีความยืดหยุ่น ความสามารถในการเกาะรวมตัว และความสามารถในการคืนตัวต่ำ แต่มีความเหนียวคล้ายยางสูง (III) เค้กที่ใช้อัตราส่วนของน้ำตาลและเนยต่ำ แต่อัตราส่วนของมาร์การีนและไข่สูง ($S_LB_LM_HE_H$) เป็นเค้กที่มีความยืดหยุ่น ความสามารถในการเกาะรวมตัว ความยากในการเคี้ยว และความเหนียวคล้ายยางสูง แต่มีความสามารถในการคืนตัวต่ำ และ (IV) เค้กที่ใช้อัตราส่วนของน้ำตาล เนย มาร์การีน และไข่ต่ำ ($S_LB_LM_LE_L$) เป็นเค้กที่มีความยืดหยุ่น ความสามารถในการเกาะรวมตัว และความสามารถในการคืนตัวสูง จากการศึกษาผลของอัตราส่วนของส่วนผสมหลักต่อลักษณะเนื้อสัมผัสของเค้กเนย (27 สิ่งทดลอง) โดยวิเคราะห์ลักษณะเนื้อสัมผัสด้วยวิธีพื้นที่ผิวการตอบสนอง (Response surface methodology) และสร้างสมการถดถอยแบบ Full quadratic model พบว่าสมการที่ได้สามารถอธิบายความสัมพันธ์ระหว่างอัตราส่วนของส่วนผสมหลักต่อค่าความยืดหยุ่นและความสามารถในการเกาะรวมตัวกันได้ดีที่สุด (r^2=0.95 และ 0.94 ตามลำดับ)

โดยเนยและมาร์การีนมีปฏิสัมพันธ์อย่างมีนัยสำคัญทางสถิติต่อค่าความยืดหยุ่น เมื่อพิจารณาจากกราฟคอนทัวร์ (Contour plot) พบว่าเมื่อใช้อัตราส่วนของเนยและมาร์การีนต่ำส่งผลให้ความยืดหยุ่นของเค้กสูง นอกจากนี้พบว่าน้ำตาลกับเนย และน้ำตาลกับไข่ มีปฏิสัมพันธ์ต่อ ค่าการเกาะรวมตัวกันของเนื้อเค้ก โดยเมื่อใช้อัตราส่วนของน้ำตาลและเนยต่ำส่งผลให้ความสามารถในการเกาะรวมตัวของเค้กสูง เมื่อใช้อัตราส่วนของน้ำตาลและไข่สูงส่งผลให้ความสามารถในการเกาะรวมตัวของเค้กสูง เมื่อนำเค้กเนยของแต่ละกลุ่มมาหาความสัมพันธ์ด้วยเทคนิคการวิเคราะห์องค์ประกอบระหว่างโครงสร้างระดับจุลภาคของเนื้อเค้ก ลักษณะเนื้อสัมผัส และคุณภาพทางประสาทสัมผัสเชิงพรรณนาวิธี Quantitative descriptive analysis (QDA) โดยใช้สเกลแบบเส้นความเข้ม 15 ระดับ พบว่า เค้ก $S_LB_HM_HE_H$ มีจำนวนเซลล์อากาศต่อหน่วยพื้นที่ คะแนนความเข้มของสีและขนาดเซลล์อากาศสูง แต่มีค่าความแข็ง ความยืดหยุ่น ความสามารถในการเกาะรวมตัว ความเหนียวคล้ายยาง ความยากในการเคี้ยว และความสามารถในการคืนตัวต่ำ เค้ก $S_LB_HM_HE_L$ มีขนาดเซลล์เฉลี่ยต่อพื้นที่ของเค้กสูง แต่จำนวนเซลล์อากาศต่อพื้นของเค้กต่ำ มีคะแนนความเข้มของสีและความแข็งสูง แต่คะแนนความเข้มของขนาดเซลล์อากาศและความสามารถในการเกาะรวมตัวต่ำ มีค่าความแข็ง ความเหนียวคล้ายยาง และความยากในการเคี้ยวสูง แต่ค่าความสามารถในการเกาะรวมตัว ความยืดหยุ่น และความสามารถในการคืนตัวต่ำ ส่วนเค้ก $S_LB_LM_HE_H$ และ $S_LB_LM_LE_L$ มีขนาดเซลล์เฉลี่ยต่อหน่วยพื้นที่ต่ำ แต่จำนวนเซลล์อากาศต่อหน่วยพื้นที่สูง มีคะแนนความเข้มของสีต่ำ แต่คะแนนความเข้มของความแข็ง ขนาดเซลล์อากาศ และความสามารถในการเกาะรวมตัวสูง มีค่าความแข็ง ความเหนียวคล้ายยาง ความยากในการเคี้ยว ความสามารถในการเกาะรวมตัว ความยืดหยุ่น และความสามารถในการคืนตัวสูง อย่างไรก็ตามเค้ก $S_LB_LM_HE_H$ มีค่าความสามารถในการคืนตัวมากกว่าเค้ก $S_LB_LM_LE_L$ นอกจากนี้เค้กเนยทุกกลุ่มที่เก็บรักษาที่อุณหภูมิ 25°C เป็นเวลา 6 วัน หรือ 4°C เป็นเวลา 18 วัน ปราศจากการเสื่อมเสียจากแบคทีเรียทั้งหมด ยีสต์และรา *Stapphylococcus aureus* และ *Bacillus cereus* เมื่อระยะเวลาการเก็บรักษาเพิ่มขึ้นพบว่า เค้กเนยแต่ละกลุ่มที่เก็บรักษาที่อุณหภูมิ 25°C และ 4°C มีค่าความแข็ง ความเหนียวคล้ายยาง และความยากในการเคี้ยวเพิ่มขึ้น แต่ความยืดหยุ่น ความสามารถในการเกาะรวมตัว และความสามารถในการคืนตัวมีค่าลดลง อัตราการเกิดรีโทรกราเดชั่นและเอนทัลปีของเค้กเนยแต่ละกลุ่มที่เก็บรักษาที่อุณหภูมิ 25°C และ 4°C มีค่าเพิ่มขึ้น ขณะที่คุณภาพทางประสาทสัมผัสมีค่าลดลงเมื่อระยะเวลาการเก็บรักษาเพิ่มขึ้น

คำสำคัญ: เค้กเนย โครงสร้างระดับจุลภาค เนย น้ำตาล มาร์การีน ไข่

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Ms. Suworanee Pancharoen

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CHAPTER 1
INTRODUCTION

1.1 Introduction

Cake is a bakery product that is delicious and widely consumed today. The market research reported in 2015 revealed that market share of bakery products and cakes in Thailand were more than 22,368 and 5,098 million baht, respectively (Food Intelligence Center Thailand, 2017). The main ingredients in cake making, including wheat flour, milk, eggs, sugar, salt, baking powder and flavor when mixing these ingredients together and heat by baking, will get a cake that looks finer and lighter (Jammek and Vinaikul, 2003). The cake is divided into three categories based on recipes and production methods, including butter cake, foam type cake and chiffon type cake. Butter cake has a crumb structure which made of emulsions of fat and liquid that occurs during the beating of butter, such as pound cake, yellow cake, chocolate cake, etc. Foam type cake is a light cake and has large air cells. The texture and the volume of the cake depend on the air bubbles produced by the egg whites, such as angel cake, sponge cake, etc. Chiffon type cake is a cake that is a combination of butter cake and foam type cake. The ingredients are egg yolks, baking powder, sugar, flour and whipped egg whites (Conforti, 2006; Lai and Lin, 2006). Moreover, cakes can be divided according to the ratio of sugar to starch ratio in the formulation into two categories, cake with a high ratio of sugar than starch (high ratio cake) such as layer cake, white cake, butter cake, angel cake, sponge cake, etc. and cake with a ratio of low sugar than starch or equal, such as pound cake, etc. (Lai and Lin, 2006).

At present, cake has a variety of recipes, for instance, commercial cake, cake recipes from books or cookbooks. It can be seen that although the cake is the same type, but the qualities of the cake, both of physical qualities and sensory qualities, are different. The qualities of the cake depend on many factors, including the types and ratios of the ingredients, the method of mixing, the duration and temperature, etc. Choosing the right ingredients and knowing the functions or properties of the ingredients is important to the qualities of cake (Conforti, 2006). Understanding the relationship between the proportion of the main ingredients used

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in making butter cakes and its quality and knowing the cluster of those cakes by clustering with the commercial butter cakes would help research planning and product development of butter cake more effectively. This will be a guideline for choosing the proper ratio of ingredients to produce the butter cake qualities that meet the requirement of consumers.

Therefore, this research aims to predict the properties of butter cakes by using the ratio of the main ingredients and to cluster groups of butter cake by its ingredients based on groups of commercial butter cake. In conducting this dissertation, the research methodology is divided into 3 steps: First, explore the commercial butter cakes and cluster them according to the physical characteristics of the cakes. Second, study the relationship between the main ingredients and the quality of butter cake. Finally, study the relationship between storage temperature and time on the qualities of butter cakes.

1.2 Research Objectives

1) To explore and clustering commercial butter cakes according to their physical properties

2) To study the relationship between the main ingredients and the qualities of butter cakes

3) To investigate the relationship between storage temperature and time on the qualities of butter cakes

1.3 Expected Benefits

1) To provide the manufacturer with an idea of how to choose the proper ingredients to produce the butter cake according to the group qualities that meet the consumer needs

2) To know the qualities changes of butter cake during storage

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CHAPTER 2
REVIEW OF LITERATURE

2.1 Types of cake

Three types of cakes were classified by formulas and production methods as following (Jammek and Vinaikul, 2003; Conforti, 2006; Lai and Lin, 2006).

1) Butter cake

Butter cake is a cake with high fat percentage. The creation of a foam structure in cake caused by beating butter, cake structure is formed by the emulsion of fat and liquid, which occurs during batter mixing. Air cell is entrapped by fat globule and expanding during baking, such as pound cake, yellow cake, chocolate cake, etc.

2) Foam cake

Foam cake is a cake with egg mixture. The texture and volume of the cake depends on the expansion of egg whites, which is beat into the bubbles and incorporate the air during the egg whipping, make the cake expanding during baking in an oven. This cake texture is light and has large air cells, such as angel cake, sponge cake, etc.

3) Chiffon cake

Chiffon cake is a cake that looks like a combination of butter cake and foam type cake. It has a fine cake crumb of foam type cake and glossy cake crumb of butter cake. But this cake is different from butter cakes because it uses vegetable oil instead of butter or margarine and uses different mixing method.

Moreover, the cakes can also be divided into 2 groups according to the ratio of sugar to starch in the cake formula as following (Lai and Lin, 2006).

1) High ratio cake

Cake with a high ratio of sugar than starch, example the ratio of sugar to starch is 1.1:1. This cake is a high fat cake such as layer cake, yellow cake, white cake, devil cake, butter cake, marble cake, etc. or cake that contains eggs as an ingredient in the formula such as angel cake, sponge cake, etc.

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2) Low ratio cakes

Cake with a ratio of low sugar or all liquid than starch or equal, such as pound cake, etc.

2.2 Ingredients and functions of ingredients

The ingredients used in making cake depend on the type of cake. The amount or proportion of ingredients indicates the qualities and characteristics of cake such as hardness, structure, moisture and flavor. The cake ingredients are divided into two categories: ingredients that give structure of cake, included wheat flour, eggs and milk, and ingredients that give cake softening, included sugar, fat and baking powder. There are also other ingredients that help in coloring and taste for cakes, such as flavoring agent, food colors, fruits, beans, cocoa and chocolate, etc. (Conforti, 2006). From review of the recipes of butter cake, it was found that the main ingredients used in butter cake were as follows: 100% wheat flour, 95-145% sugar, 30-130% butter, 10-75% margarine, 30-140% egg, 40-100% milk, 0.2- 4% salt, 2-6% baking powder, and 1-5.5% flavor (all ingredients are calculated by percent of weight flour.) (Jammek and Vinaikul, 2003; Jullaya, 2009; Kongphan, 2000; Thongtungwong and Suwonsichon, 2010; Pyler, 1988; Cauvain and Young, 2006; Kocer et al., 2007; Hicsasmaz et al., 2003; Chesterton et al., 2012; Wilderjans et al., 2013; Meza et al., 2011)

2.2.1 Flour

Wheat flour is the main ingredient used in making cakes. Wheat flour used to make the cake is mostly grinding of soft wheat because of its low protein content, about 7-9 percent. The flour is fine, has the ability to absorb water, less resistant to mixing and fermentation than hard wheat flour, and it was bleached so it is more ability to absorb water, sugar and fat than unbleached flour (Jammek and Vinaikul, 2003). Cake flour should have a protein and ash 8.5$\pm$0.5 and 0.36$\pm$0.04 percent, respectively, pH 4.7$\pm$0.2, particle size of starch 10$\pm$0.5 micrometer. Wheat flour, which used for making layer cake, yellow cake, white cake and chiffon cake should have protein and ash 7.35 and 0.29 percent, respectively (Pyler, 1988). Wheat flour contains two types of protein: glutenin and gliadin. When combined with the

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right amount of wheat flour and water, they produce gluten, which is sticky and flexible. Glutenin gives dough flexibility and gliadin make dough expansion (Conforti, 2006). Moreover, gluten is also found in other grains, such as barley, rye, corn, etc.

Flour provides structure and texture of cake. The role and function of flour during mixing, flour has an ability to absorb water well. When the starch is mixed in the batter, the particles of the starch swell up, causing batter more viscosity and less coalescence of fat and air cells in the batter, resulted the batter to have more stable. In addition, during mixing, gluten is formed but not as much in bread, because cake ingredients contain a large amount of liquid ingredients, such as egg and milk, due to the viscosity of cake batter is lower than bread dough. The previous study, adding gluten protein could increase batter viscosity, improving during baking capacity of batter to expand air cell and produce the cake volume (Wilderjans et al., 2008). Moreover, increasing gluten levels in the cake recipes give the cakes resistance to collapse, resulting in desirable volumes and an optimal grain structure with uniform cell distribution (Hesso et al., 2015b). During baking, the temperature inside the batter is higher, increasing starch granules swell up and binding to the structure of the bricks and mortar of cake (Wilderjans et al., 2013). The volume of the cake depends on the gelatinization temperature of starch, moisture and sugar content. By that, during baking, the temperature inside the batter is higher, swollen starch granules were increasing and binding to the cake structure (Wilderjans et al., 2013; Cauvain and Young, 2006) Water around the outer surface of the cake evaporates, resulting in a lack of gelatinization of starch on the outer surface of cake, which make the outer surface of cake to dry and solidify as a crust (Kerckhofs et al., 2010). Starch gelatinization is an important key during baking representing the major ingredient in bakery products; it contributes to the textural and structural characteristics of the products. (Zanoni et al., 1995)

2.2.2 Eggs

Eggs are an important ingredient in making cakes, contributing to the structure, color, flavor, moisture and nutritional value. They consist of 58% egg white and 31% egg yolk, the rest is egg shell (11%). Egg white consists mainly of water up to 88% and 11% protein. There are over 40 types of protein in egg whites, such as 54% ovalbumin, 12% ovotransferrin, 11% ovomucoid, 8% globulins and 3.5% lysozyme

(Wilderjans et al., 2013). Eggs provide multifunction in cake making in that it contributes in stabilizing the gas cell migration from fat to the aqueous phase (Hesso et al, 2015). When whipping egg white, it forms a foam, which consists of small bubbles, as proteins in the egg whites are broken down, formed and trapped air inside (Conforti, 2006). Egg yolks have high nutritional value, consist of 50% water, 34% fat and 16% protein. Fat in the egg yolk contains 66% triacylglycerols, 28% phospholipid, 5% cholesterol and other minerals (Wilderjans et al., 2013). Egg yolk cannot be beaten and turned into foam like egg white because of its high fat content, which prevents the formation of proteins structure (Conforti, 2006). In addition, egg yolks also help to make the cake look more yellow crumb in cake product such as sponge cakes, yellow cakes, etc. During mixing, batter will be in the form of emulsion that is stable. Large particles of fat are beat to a small size and have less surface tension at the oil-water interface. When mixing the egg in the batter, egg proteins form protein network and trap the air cell, which prevents aggregation into large air cells. Protein in egg yolks, lipoprotein acts as an emulsifying agent, reducing the surface tension at the oil-water interface, caused the batter more stable (Pyler, 1988). When baking, batter will solidify due to the gelatinization of starch and the formation of egg protein. When heated, the protein denatures and forms a new bonding structure (Wilderjans et al., 2013). Ovalbumin in egg whites denature at 85°C and lipoprotein in egg yolks denature at 65°C (Kiosseoglou and Paraskevopoulou, 2006). In addition, Hesso et al. (2015b) studied the role of ingredients on the qualities of cake. It was found that increasing the amount of eggs and starch in the mixture, due to increased protein, resulted in increase of viscosity. This prevents loss of air cells and makes the batter more stable. In addition, egg white contains 85% moisture which therefore gives moisture to the cake. The protein in egg yolk coagulates and increases the viscosity of the batter to form a solid structure of the cake during baking and may affect the texture and other qualities of cake (Hesso, 2015; Marcet et al., 2016)

2.2.3 Fats

Fat is an important ingredient in baking products in providing their texture properties. The functions of fat in cake making are to envelope the air cells while mixing the ingredients, to enrich protein particles and starches to disperse well in the batter, resulting in a soft texture and moist cake crumb (Pyler, 1988). When

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beating butter and sugar together, the mixture formed cream with water in oil emulsions and trapped the air cells. Crystals form that are able to trap air cells must have small crystals about 1-2 micrometers in diameter and are in the form of β' disperse around the air cell (Ghotra et al., 2002). When the batter is baked, the crystals form will be melted. Some fat crystals entrap the air cells, but most fat crystals become oil droplets disperse around in aqueous phase. After that, the batter is increase viscosity of batter, air cells are closer to each other, but they do not bind together because the egg yolk protein, the lipoprotein, acts as an emulsifying agent, thus reducing the surface tension at the oil-water interface (Wilderjans et al., 2013).

There are many types of fat in cake making such as butter, margarine, shortening, etc. Butter is a dairy product made from churning milk or cream, contains 80-81% butter fat, 16-18% water and 1-1.5% curd (protein, lactose and minerals) and 0-1.5% salt. Moreover, it contains 83.2% saturated fat and 58.8% of total fat content (Albert et al., 2008). The addition of salt depends on the type of butter that is added the salt or not (Suraphat, 2009). Butter is popularity to use in cake products because of its sensory properties, nutrients value and naturalness of consumers' mind. The creaming properties of butter are relatively poor and it may require the supplement with an emulsifier in order to get the best qualities. Margarine is a non-dairy product created as a substitute for butter, made from vegetable fats. It is liquid or semi-liquid at room temperature through hydrogenation process, contains more saturated fatty acids and changes from liquid to semi-solid. Margarine has 79% fat, saturated fat and trans fat content of 19.6% and 6.6% of total fat content, respectively (Albert et al., 2008). Margarine is water in oil emulsion with butter like texture, adding salt, colorants and vitamins to provide sensory quality and nutritional value close to butter (Suraphat, 2009). The composition of margarine is similar to butter, but the mixture of oils, milk solid, water, salt and functionality of different margarine are various. Margarine may contain an emulsifier to aid the dispersion and stability of the water phase (Rodríguez-García et al., 2014; Alberts et al., 2006)

2.2.4 Sugar

Sugar or sucrose is a disaccharide, consists of one molecule of glucose linked to one molecule of fructose with glycosidic bond. Sugar is crystalline organic compound that is soluble in water and has sweet taste. Most of sugar

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produced in Thailand is made from sugarcane. Sugar is a sweetener, moisture, soft, help to whip cream and eggs to be stable, volume up and make brown to cake products (Cauvain and Young, 2006). Sugar used to make cake is generally three types: first type, white sugar is usually used to make bakery products, the three different crystal size of sugar is normal, big and fine. The sugar used to make the cake should be fine crystal and mixed with other ingredients well. If the sugar is big and rough, when the cream is beaten with butter, it will not dissolve and remain crystalline, the cake will have small hole in crust. Second type, icing sugar is fine powder sugar with about 3% corn starch to prevent chunking or crystallization of sugar. The use of icing sugar in cakes makes the cakes look finer and lighter than normal sugar. And the last type, brown sugar is a non-bleached, finely powdered or agglomerate, the color is lightly brown to dark brown, with a high moisture content (0.7-3.0%) and minerals. This type of sugar gives flavor and color, making the product darker brown. Most of them are not used in light cakes, but use in cakes like caramel flavor and brown color, such as fruit cake (Jammek and Vinaikul, 2003).

The functions of sugar are increasing the volume of cake by incorporation of air into the fat during creaming. During baking, the temperature of sugar raises at which the gelatinization of starch occurs, and helps the cake crust color becomes progressively darker through caramelization and maillard reaction (Rodríguez-García et al., 2014; Conforti, 2006; Cauvain and Young, 2006). The concentration of sugar in cake batter had effect on the gelatinization of starch. Adding 55-60% of sugar in the cake formula resulted in an increasing of a gelatinization temperature from 57 to 92°C, surface hardening of the cake, and collapsing (Kim and Walker, 1992). Moreover, sugar effect protein denaturation by changing the hydrophobic interaction inside a protein and conferred resistance against denaturation to form protein network on the structure of cake (Wilderjans et al., 2013; Hesso et al., 2015b). This finding is in agreement with the previous work, adding sugar and egg increased the temperature of protein denaturation (Hesso et al., 2015a) and adding 40% of sugar could increase 6-8°C (Kulmyrzaev et al., 2000). Moreover, high level of sugar increased the starch gelatinisation temperature to a point where the cake did not set and collapse during baking (Wilderjans et al., 2013).

The functions of sugar are increasing the volume of cake by incorporation of air into the fat during creaming. During mix the ingredients, sugar is beaten to a smaller size and grasped with a crystalline fat crystals of 1-2 microns. This result made fat crystals to be smaller crystalline fat crystal. When the eggs are mixed in the mixture, sugar is bound to the protein structure, making the batter more viscous (Wilderjans et al., 2013). During baking, the temperature of sugar raises at which the gelatinization of starch occurs, and helps the cake crust color becomes progressively darker through caramelization and maillard reaction (Rodríguez-García et al., 2014; Conforti, 2006; Cauvain and Young, 2006). The concentration of sugar in cake batter had effect on the gelatinization of starch. Adding 55-60% of sugar in the cake formula resulted in an increasing of a gelatinization temperature from 57 to 92°C, surface hardening of the cake, and collapsing (Kim and Walker, 1992). Moreover, sugar effect protein denaturation by changing the hydrophobic interaction inside a protein and conferred resistance against denaturation to form protein network on the structure of cake (Wilderjans et al., 2013 and Hesso et al., 2015b). This finding is in agreement with the previous work, adding sugar and egg increased the temperature of protein denaturation (Hesso et al., 2015a) and adding 40% of sugar could increase 6-8°C (Kulmyrzaev et al., 2000). In addition, when increasing the concentration of sugar by 10% will increase the denaturation temperature of egg white protein with approximately 2°C. Because sugar absorbed water in the system and resulted in decreasing of free water. In addition, sugar also affects the stability of protein, resulted in more hydrophobic interaction of the amino acids (apolar amino acids) and reduced the occurrence of protein denaturation. Moreover, high level of sugar increased the starch gelatinization temperature to a point where the cake did not set and collapse during baking. If the ratio of sugar to water is more than 50%, cake will have a good volume, small and uniform air cells (Wilderjans et al., 2013).

2.2.5 Milk

Milk is a rich nutrient food, consist of 87.1% water, 3.3% protein, 3.9% fat, 5.0% sugar and 0.7% minerals, has 12.9% total solids and 9% non-fatty solids of total solids content. Important proteins in milk are divided into two groups: casein and protein, act as an emulsifier linking between the layers of fat and water. The sugar in milk is lactose, disaccharide of glucose and galactose (Suraphat, 2009). Milk is a

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liquid ingredient, mixs other ingredients together during mixing, dissolves sugar, help baking powder reaction, controls the viscosity and temperature of mixture (Jammek and Vinaikul, 2003). Proteins in milk form bonds to the mixture, thus trapping small air cells during baking, resulting in a good volume of cakes. It makes cake moistness, because protein and sugar in the milk absorb water to evaporate less during baking. Furthermore, protein and sugar in milk also help making the cake brown color and giving the flavor from maillard reaction (Figoni, 2008).

2.2.6 Salt

Salt emphasizes the flavor of ingredients to be more pronounced, and make the cake more hard texture because salt affects the dough gluten and builds the structure of cake (Jammek and Vinaikul, 2003). It also reduce the amount of free water, prevents the growth of microbiological and fungi (Cauvain and Young, 2006)

2.2.7 Baking powder

Baking powder is a chemical compound used as a food additive. The main purpose is to make bakery products to have good volume such as cakes, donuts, cookies, etc. Baking powder is chemically called sodium bicarbonate or sodium hydrogen carbonate ($NaHCO_3$). It is a white solid and crystal structure, but look like fine powder, alkaline property which contains sodium bicarbonate and acidic substances, such as acid calcium phosphate monohydrate (ACP), tartaric acid, sodium acid pyrophosphate (SAPP), sodium aluminiumphosphate (SALP), potassium hydrogen tartrate (cream of tartar), glucono-delta-lactone (GDL) and anticaking agent to prevent direct reaction between the two substances. When baking powder is heated over 70°C, it gradually decomposes into sodium carbonate (Na_2CO_3), water and carbon dioxide (CO_2). This decomposition reaction occurs at a temperature of 250°C (Cauvain and Young, 2006), as shown in Equation 2.1

$$2\ NaHCO_3 \xrightarrow[\Delta]{} Na_2CO_3 + H_2O + CO_2 \qquad \text{--------------} \ 2.1$$

The quality of baking powder depends on the carbon dioxide releasing from sodium bicarbonate and types of acidic substance that controls the rate of reaction and baking temperature. Baking powder is divided into two types based on the carbon dioxide releasing rate. There are single action baking powder and double action baking powder. Single action baking powder contains a single acidic substance, such as potassium hydrogen tartrate, which produces carbon dioxide quickly while mixing and baking. Double action baking powder contains two or more acidic substances, such as sodium acid pyrophosphate, sodium aluminum phosphate, etc., which produce carbon dioxide at different temperatures. An acid is reacted at low temperatures, making the batter raise up during the mixing step. And another acid reacts at high temperatures, causing the batter raise up again while baking in the oven. The amount and type of baking powder affects the qualities of cake. When adding more baking powder, cake will have a higher volume and have more porous structure. However, if using too much baking powder, cakes could be collapse (Jammek and Vinaikul, 2003 and Cauvain and Young, 2006).

2.2.8 Emulsifiers

Emulsifiers are substances that help emulsion stabilize, such as reducing the surface tension of liquid emulsion and so does not separate layers, distribution the particles of oil droplets or water droplets into the liquid phase. In bakery products, using emulsifiers for softness and increasing volume, making the texture smoother and more homogeneous, improving the quality of bread, absorbing water which making bakery products more moisture and extending the shelf life of the products (Leyn, 2006). Emulsifiers used in cake products are of various types such as glycerol monostearate, polysorbate, Propylene glycol, diacetyl tartaric acid ester of monoglycerides (DATEM), etc. Glycerol monostearate (GMS) is a widely used emulsifier. It isusually used in the form of alpha-crystalline which allows the bubbles in the batter to stabilize and not coalesce, make the cake more volume, finer and softer texture (Cauvain and Young, 2006). Propylene glycol monostearate (PGMS) is an emulsifier used in food products a long time, usually used in sponge cake, it helps increase in cake volume and improve the cake texture to be more uniform and moist (Fleming and Niels, 2004). DATEM is an ester of diacetyl tartaric acid (DATA), usually used in bakery products, it helps keep the bubbles in the batter more stable and prevent the bubbles forming during baking which help improve the cake texture (Cauvain and Young, 2006). Ashwini et al. (2009) found that the addition of xanthan gum and GMS increased batter viscosity, specific gravity, cake moisture and volume, but decreased hardness ($p \leq 0.05$). Zhou et al. (2011) studied the effects of emulsifier types such as PGMS, GMS and lecithin on cake qualities. It was found that three types of emulsifiers reduced the specific gravity of the batter. Cakes added PGMS and GMS had more volume, less hardness and higher consumer liking score. When cake was stored for 12 days, cake containing PGMS, GMS and lecitol with 3% of flour weight had the lowest hardness ($p \leq 0.05$).

2.3 Cake mixing method

2.3.1 Mixing

Mixing purpose is to make all the ingredients homogeneous, incorporate air cells in the batter and make the batter with the least in gluten forming. The method of mixing is related to the type of cake, which has different ingredients, mixing time, mixing speed, the order of each ingredient and mixing temperature. Butter cakes have variety methods, including creaming method, blending method, and single stage method (Pyler, 1988). The most method used to make butter cake is creaming method. The first step is to mix fat, butter or margarine, with sugar at low or medium speed to make the mixture homogeneous and creamy with water in oil emulsion properties and the air cell are trapped. The second step is to add eggs and beat them at low speed until the ingredients mixed together, batter will look like oil in water emulsion. The last step is to mix the liquid (water or milk) and flour alternately until the batter is smooth at low speed. The batter will have a complex structure in which the sugar and egg protein build up the structure in the form of aqueous phase, starch particles in dispersed phases and air cells in lipid phase (Wilderjans et al., 2013) as shown in Figure 2.1.

2.3.2 Baking

Baking involves heating the liquid inside the batter to vaporize, increases vapor pressure in the air bubble which led to expansion of the cake volume. Air cells and the carbon dioxide that are produced during the mixing process. As the temperature of the batter rises in the oven, it allows the batter to expand and make the cake volume raise up. Baking causes denaturation of protein and coagulation. Gelatinization occur when starch is heated (Lai and Lin, 2006). During heating, crust begins to turn brown and hardens slowly. The moisture in the cake gradually

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evaporates. When baked for a while, the texture of cake crumb will be harder and turn into light brown while the crust is more harden and turns darker brown (Pyler, 1988). The hardening of the cake will be harder at the bottom of the cake than at the top and center of the cake (Wilderjans et al., 2010).

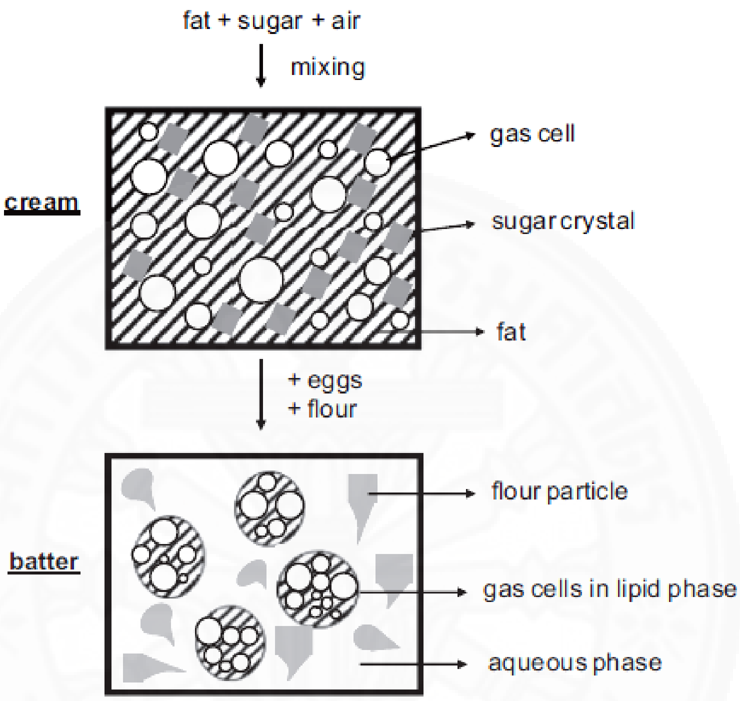

Figure 2.1 The appearance of cream derived from the beating fat and sugar and the final batter of butter cake by creaming method

Source: Wilderjans et al. (2013)

The optimal conditions for baking cakes are involved by many factors, such as sugar or milk used in the batter, the fluid of batter, cake pan size, etc. General method for baking cake, if the batter contain high sugar content, low temperature for baking and long time will be used. Each type of cake has different ingredients. Therefore, the temperature and baking time are varied. The appropriate temperature and baking time for common cakes are shown in Table 2.1. The temperature inside cake during baking should be between 98.3 and 98.9°C (Pyler, 1988).

Table 2.1 The optimum temperature and baking time for baking cakes

Cake types	Baking temperature(°C)	Baking time (min)
pound cake	163 - 185	50 - 65
layer cake	185 - 190	20 - 25
sponge cake	199 - 216	10 - 20
angel cake	177 - 204	30 - 45
chiffon cake	177 - 190	30 - 45

Source: Pyler (1988)

2.4 Degradation of cake qualities and shelf life

The preventing of degradation of bakery products is the way to slow down all of qualities, including texture qualities of the cake. There are many ways to prevent degradation in bakery products, such as storage at low temperature (chilled or frozen), radiation drying, vacuum packing, using chemicals and using different ways in combination. Cake products can be stored longer depending on formulation, packaging, water activity and storage temperature. Good qualities of cake are consisted of many attributes, including high volume and softness. Because cake balancing formula is generally low in specific volume and firmness, ingredients, such as sugar and fat, affect the softness of cake and eggs effect on cake firmness (Phuwarodohm, 1995). Degradation of bakery products can be devided into three types.

2.4.1 Staling

Staling is associated with qualities degradation, caused by both physical and chemical changes, which make the crust sticky, crunchy cake crumb and color change without water loss, strange smell. Amylose is separated from starch and formed as turbid sediment, and gluten loses water. Staling begins since the cake come out of the oven. After the cake is removed from the oven to cool, amylose molecule reorganizes the molecule with a three-dimensional hydrogen bond. The structure that can hold water but cannot absorb water again. The viscosity of the batter is more stable and occurs a crystalline structure is called “Retrogradation”. Staling is a change after baking. It is a reaction caused by the movement of water from the cake crumb to the surface of the cake and changes in the composition of lipid and protein polymers inhibited aggregation of amylose and amylopectin. Therefore, the ingredients of making cake are important for staling, such as cookies and biscuits have more fat than bread which occurs less staling. Staling causes the changing sensory qualities of cake such as taste, feeling in the mouth and appearance. Cake could change to be harder, more dry and more crumbly. Therefore, bakery products that have high moisture after baking such as bread and cakes, are easier to staling than low moisture products such as cookies and crackers. Cake generally has the storage times of 1-4 weeks or more, depends on the ingredients, water activities and storage temperature. The factors that influence the occurrence of staling are shelf life and storage temperature. Cakes stored at 20°C will have a shorter shelf life than cakes stored at 4°C (Smith, 1993; Srirot and Piyajomkwan, 2003).

Based on the study of staling in cakes by Hesso et al. (2015a), cake stored at 20°C for 25 days was retrograded by changing the fat recrystalline into β-form rather than the cakes stored at 4°C. Therefore, storage of cake at low temperature (4°C) resulted in staling slower than storage at high temperature.

From the study of bread staling, the temperature and baking time of 180°C, 34 minutes and 220°C, 28.6 minutes were investigated. The Avrami equation as in Equation 2.2 was used to study the rate of staling or the rate of increasing in hardness of bread. It was found that bread was baked at high temperature and short time had higher rate of retrogradation than baked at low temperature and long time. The rate of retrogradation of bread was the first reaction (n = 1) (Besbes et al., 2014).

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$$\theta = \frac{X_\infty - X_t}{H_\infty - H_0} = \exp(-kt^n) \qquad \text{-------------- 2.2}$$

Where θ is rate of retrogradation

X_t is enthalpy at times of staling(t)

X_0 is enthalpy at zero day of staling (t=0)

X_∞ is enthalpy at the last day of staling ($t=\infty$)

k is rate constant

n is reaction rate

2.4.2 Increase or decrease of moisture

Bakery products generally have a relative humidity value of about 78 to 97% (or a_w 0.78-0.97). When stored in the air, it is tended to loss water, resulting in crumbly and dry texture. Some products contain flour and cream or fillings with varying moisture content, moisture transfer between each other makes the texture moist or dry. In addition, packaging of bakery products in closed containers, may occur water drops inside the container, causes the product to become wet, fungi grows more easily. This problem can be solved by selecting the appropriate packaging material (Phuwarodohm, 1995).

2.4.3 Microbiological spoilage

Microbiological spoilage is the most important cause of staling bakery products. The most important microbiological organism is fungi. In some cases, bacteria and yeast may be contaminated by uncleaned equipment or poor worker hygiene. The commonly found bacteria are *Serratia marcescens, Leuconostoc mesenteroides, Bacillus licheniformis* and *Bacillus mesentericus.* Bacteria that cause food poisoning are rarely detected. If it is occurred, most are from cream cakes such as *Stapphylococcus aureus, Bacillus cereus* and *Samonella*, etc. Detected yeast is usually an osmotic pressure-resistant species such as *Saccharomyces bailii var. osmophilus*, gives alcohol and carbon dioxide. Since fungi is the most important cause of spoilage, the shelf life of bakery products is usually determined from the time that no fungi is observed on the product, called “Mold free shelf life” (Smith, 1993).

2.5 Cluster analysis

Cluster analysis is a technique used to classify or categorize a case (people, animals, objects or organizations, etc.), or to divide the variable into two or more subgroups. Case of the same group has the same or similar characteristics, while the different cases are different. Cluster analysis has no mechanism for differentiating between relevant and irrelevant variables. Therefore the choice of variables included in a cluster analysis must be underpinned by conceptual considerations. This is very important because the clusters formed can be very dependent on the variables included. In grouping, it can use either mathematical methods or diagrams. The variables in the same group are more correlated than those in the different groups. Variables in different groups are less related or unrelated. All cluster analysis techniques have the same conditions. But the technique divides the same or similar cases in the same study and can be applied to all variables, both quantitative and group variables. This can be divided into two techniques. (Vanichbancha, 2005; Everitt et al., 2001)

2.5.1 Hierarchical cluster analysis

It is a very popular technique for grouping, the results of this technique did not provide statistical or hypothesis testing, which results in determining the optimal number of clusters. The analysis needs to be considered appropriately. The distance or similarity may be used by using a dendrogram, where the analyst can determine the number of groups from the dendrogram by specifying distance or similarity criteria as a basis for decision making, the use of Hierarchical cluster analysis has the following conditions: in cases where the case is divided, the number of cases and the number of variables must not be too low, should be less than 200. No need to know the number of groups before. There is no need to know which variable or case of any group. Data analysis does not require standardized data (Vanichbancha, 2005).

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A number of different methods used to determine which clusters should be joined at each stage. There are 5 main methods: (Everitt et al., 2001)

1) Nearest neighbour method (single linkage method)

The distance between two clusters is defined to be the distance between the two closest members, or neighbours. This method is relatively simple but is often criticised because it doesn't take account of cluster structure and can result in a problem called chaining whereby clusters end up being long and straggly. However, it is better than the other methods when the natural clusters are not spherical or elliptical in shape.

2) Furthest neighbour method (complete linkage method)

The distance between two clusters is defined to be the maximum distance between members, example the distance between the two subjects that are furthest apart. This method tends to produce compact clusters of similar size but, as for the nearest neighbour method, does not take account of cluster structure. It is also quite sensitive to outliers.

3) Average (between groups) linkage method (sometimes referred to as UPGMA)

The distance between two clusters is calculated as the average distance between all pairs of subjects in the two clusters. This is considered to be a fairly robust method.

4) Centroid method

The centroid (mean value for each variable) of each cluster is calculated and the distance between centroids is used. Clusters whose centroids are closest together are merged. This method is also fairly robust.

5) Ward's method

This method all possible pairs of clusters are combined and the sum of the squared distances within each cluster is calculated. This is then summed over all clusters. The combination that gives the lowest sum of squares is chosen. This method tends to produce clusters of approximately equal size, which is not always desirable. It is also quite sensitive to outliers. Despite this, it is one of the most popular methods, along with the average linkage method.

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2.5.2 K-means clustering

It is a case classification technique that is used when there are a large number of cases. It required number of groups or clusters. The variable used is a quantitative variable, interval or ratio scale. It cannot be used for frequency or binary data like Hierarchical. It is sometimes preferred because it allows subjects to move from one cluster to another (this is not possible in hierarchical cluster analysis where a subject, once assigned, cannot move to a different cluster). K-means clustering is a rather difficult method because it is often difficult to know how many clusters you are likely to have and therefore the analysis may have to be repeated several times. Moreover, it can be very sensitive to the choice of initial cluster centres. So, it may be worth trying different ones to see what impact this has. The use of K-Means has the following conditions: used when has a large amount the number of cases or data, should be more than 200 cases. A certain number of groups must be predefined. Data analysis needs to be standardized before data. This method will find the distance using the Euclidean distance method (Vanichbancha, 2005; Everitt et al., 2001).

2.6 Microstructure study by using a Stereo microscope and image analysis by using ImageJ

2.6.1 Stereo microscope

Microscopes can be divided into two broad categories: optical microscopes and electron microscopes. Stereo microscope is an optical microscope, the image appears as a three-dimensional image, the width, length and thickness. The light that shines the object comes from all directions, then reflected back into the camera or from beneath the shining object can shine through. The choice of lighting depends on the nature of the object being inspected, that it looks opaque or transparent. This microscope can adjust the sharpness of the image in the height of the various sample levels. The principal of stereo microscope is brought two compound microscope combine together by tilting the angle of 15 degrees to each other, which make the image appear as a 3D image, the magnification of the camera is about 20-80 times. Adjust the power of the image by turning the zoom lens until the size of the image is clear. Expansion of the image by the magnification of the lens

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multiply the zoom magnification with the zoom lens. Adjusting the contrast of the images by using only the rough adjustment button alone (Wikipedias encyclopedia, 2016; Wangsomnueg, 2017).

2.6.2 Image analysis by using ImageJ

Image analysis is a technique to description converting the 2D or 3D images into other forms that can be used to characterize their content. There are many program to analyze image. ImageJ is a program usually used to analyze image from 3D to 2D cell image processing, multiple imaging system data comparisons to automated number of cell per area, cell size and average cell size. The method is using the contrast between two phases (pore and solid) in the image, convert color of image to gray scale. Then, use bars of known length, pixel value were converted into distance units. Crop the image and specify the area that want to analyze, and then adjust to threshold, the picture will show the red area of pore and program will show the ellipse of air cell and result the data of number of cell per area, cell size and average cell size (Turabi et al., 2008; Wilderjans et al., 2008).

Ashwini et al. (2009) investigated the effects of hydrocolloid and emulsifier on the structure of eggless cake using a scanned electron microscope (SEM) of 1,500 times magnification. The cake with hydroxypropyl methylcellulose (HPMC) and glycerol monostearate (GMS) made the best cake qualities. The structure of the cake crumb is in two forms: large starch granules with round shape, and small starch granules with small square shaped, which was distributed in the structure of gluten and protein networks.

Turabi et al. (2010) studied the effect of gum type on cake qualities (cake texture, average pore cell area, pore cell density and pore dimensions) using a SEM of 30 and 500 times magnification. When the image was converted to binary image, the pore size is clearly visible and can be counted. In addition, when using a 30x magnification microscope image to study the surface texture of the cake by image analysis, it was found that the cake containing xanthan gum had the maximum of small porosity of 0-0.5 mm^2 and total number of pore cell. It also showed that cake had small pore cell distribution. Because xanthan gum is a viscosity enhancer and stabilizer and make the particles suspended well; therefore, it is possible to keep air trapped during the baking process and cake will have small air cells throughout the cake structure.

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CHAPTER 3
RESEARCH METHODOLOGY

3.1 Raw materials

3.1.1 Ingredients for making cake

3.1.1.1 Cake flour (Royal fan®, United flour mill Public Co., Ltd., Thailand)

3.1.1.2 Fresh eggs number 1 (CPF®, Charoen Pokphand Co ., Ltd., Bangkok, Thailand)

3.1.1.3 Baking powder (Best foods®, Double acting formula, Unilever Bestfoods (Thailand) Ltd., Thailand)

3.1.1.4 Vanilla essence (Winner ®, Great hill Ltd., Part., Thailand)

3.1.1.5 Evaporated milk (Carnation®, Nestle (Thai) Ltd., Thailand)

3.1.1.6 Salt butter (Orchid®, Thai milk industry Co., Ltd., Thailand)

3.1.1.7 Margarine (Zest®, Lam Soon Public Co., Ltd., Thailand)

3.1.1.8 Salt (Prung Thip®, Pure salt industry Co., Ltd., Thailand)

3.1.1.9 Sugar (Mitr Phol®, Mitr Phol sugar Co., Ltd., Thailand)

3.1.2 Commercial butter cakes

The commercial butter cakes used in this experiment were purchased from department stores, convenience stores and bakery shops in Bangkok, Pathum Thani and Nonthaburi provinces. The sliced cake with the thickness not greater than 3 centimeters, kept in the packaging and was manufactured no later than 3 days from manufacture, were selected.

3.1.3 Reference products for quantitative descriptive analysis (QDA)

3.1.3.1 White bread (Farmhouse®, President bakery Co., Ltd., Thailand)

3.1.3.2 Stick biscuit (Lotus®, Srinanaporn marketing Co., Ltd., Thailand)

3.1.3.3 Puff makeup (Camella®, Unique fashion Co., Ltd., Thailand)

3.1.3.4 Puff cleanser (Camella®, Unique fashion Co., Ltd., Thailand)

3.1.3.5 Jelly dessert with fruit flavor (Pipo®, European food public Co., Ltd., Thailand)

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3.1.3.6 Wafer (Laisanne®, URC (Thailand) Co., Ltd., Thailand)

3.1.3.7 Khanom phing (Kanom BanArjarn®, Thailand)

3.1.3.8 Butter cake (S&P®, S&P syndicate public Co., Ltd., Thailand)

3.1.3.9 Butter essence (Winner ®, Great hill Ltd., Part., Thailand)

3.1.3.10 Sugar (Mitr Phol®, Mitr Phol sugar Co., Ltd., Thailand)

3.1.3.11 Salt (Prung Thip®, Pure salt industry Co., Ltd., Thailand)

3.1.3.12 Sugar-butter bread (Farmhouse®, President bakery Co., Ltd., Thailand)

3.1.4 Reagent for chemical analysis

3.1.4.1 Hydrochloric (Merck®, Merck KGaA, Germany)

3.1.4.2 Sulfuric acid (Merck®, Merck KGaA, Germany)

3.1.4.3 Thiobarbituric acid in glacial acetic acid (Merck®, Merck KGaA, Germany)

3.1.5 Reagent for microbiological analysis

3.1.5.1 Standard plate count agar (PCA; Merck®, Merck KGaA, Germany)

3.1.5.2 Cereus selective agar base ACC mossel (Merck®, Merck KGaA, Germany)

3.1.5.3 Baird parker agar base (Merck®, Merck KGaA, Germany)

3.1.5.4 Dichloran rosebengal chloramphenicol agar (Merck®, Merck KGaA, Germany)

3.1.5.5 Polymixin B selective supplyment (Merck®, Merck KGaA, Germany)

3.1.5.6 Egg yolk emulsion (Merck®, Merck KGaA, Germany)

3.1.5.7 Egg tellurite emulsion (Merck®, Merck KGaA, Germany)

3.1.5.8 Sodium chloride (Merck®, Merck KGaA, Germany)

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3.2 Equipments

3.2.1 Equipment for butter cake preparing

3.2.1.1 KitchenAid mixer (KitchenAid®, model 5K5SS, U.S.A)

3.2.1.2 Electric oven (Union progress®, Thailand)

3.2.1.3 Analytical balance 2 digit scales (Satorius®, model CP4202s, Germany)

3.2.1.4 Kitchen accessories (Including measuredspoon, measured cup, spatula, sieving flour pan, baking paper, cake pan, metal tray, rack, rubber pie, knife, plate and bowl)

3.2.2 Equipment for physical analysis

3.2.2.1 Colorimeter (Colorflex®, model Hunter lab CX2687, USA.)

3.2.2.2 Texture analyzer (Model TA-XT2i, Stable micro system, Chapra techcenter Co. Ltd., USA.)

3.2.2.3 Water activity meter (Aqua lab®, model CX2, USA.)

3.2.2.4 Stero microscope (Olympus®, model SZX7, Japan)

3.2.3 Equipment for chemical analysis

3.2.3.1 Differential scanning calorimeters (Model DSC1 star^e system, Mettler Toledo, USA.)

3.2.3.2 Water Bath (Memmert, Model WB22, Germany)

3.2.3.3 Distillation Unit (Buchi, Model B-324, Buchi Labortechnik AG, Switzerland)

3.2.3.4 Extraction Unit (Soxtoc, Model 2050, Tecator, Sweden)

3.2.3.5 Spectrophotometer (Hitachi®, Model UH5300, Japan)

3.2.4 Equipment for microbiological analysis

3.2.4.1 Incubator (Clayson®, Clayson laboratory apparatus Pty Co. Ltd., Australia)

3.2.4.2 Incubator (Binder®, model KB 240, Binder Co. Ltd., Germany)

3.2.4.3 Analytical balance (Mettler®, model K5SS, USA.)

3.2.4.4 Autoclave stream sterilizer (Tuttnauer®, model 3850M, USA.)

3.2.4.5 Refrigerator (EVERmed®, model LR 925S, Via Galieo Galilei 2, Italy)

3.2.5 Equipment for sensory evaluation

3.2.5.1 Equipments for sensory evaluation include water glass, trays and stationery

3.2.5.2 Questionnaires (According to appendix A)

3.2.6 Software for analysis

3.2.6.1 SPSS 20.0 for windows version (SPSS Co., Ltd, Thailand)

3.2.6.2 XLstat version 2007 in microsoft excel for windows version (Addinsoft, USA)

3.2.6.3 ImageJ (http://imagej.nih.gov/ij)

3.3 Method

3.3.1 Clustering of commercial butter cakes products

3.3.1.1 Sampling of commercial butter cakes products

The commercial butter cakes which were available from department stores, convenience stores and bakery shops in Bangkok, Pathum Thani and Nonthaburi provinces were explored. The sliced cake with the thickness were not greater than 3 centimeters, kept in the packaging and was manufactured no later than 3 days from manufacture, were selected. The manufacturer, brand, product name, package and price of the selected cake were recorded. The experiment was repeated with 2 replications.

3.3.1.2 Analysis of physical properties of commercial butter cakes

a) Specific volume

Specific volume of cake was determined using the seed displacement method (AACC, 2000). The empty pan was filled with sesame seeds and their volume determined by graduated cylinder (V_1). The butter cake was placed in a pan and filled with sesame seeds. The volume of sesame seeds was determined by graduated cylinder (V_2). The specific volume was then calculated using equation 3.1

$$\text{Specific volume} = \frac{V_1 - V_2}{\text{sample weight}} \qquad \text{-------------- } 3.1$$

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b) Texture profile analysis (TPA)

The crust of sliced cake sample was removed and the sample size of 40 x 40 x 20 mm was used for texture determinations. The cake crumb texture was analyzed by Texture profile analysis (TPA) according to the method of Gómez et al. (2010) with an instrumental texture analyzer with a 25 mm diameter cylinder probe. The cake samples were compressed by 10 mm (50% deformation) at a test speed of 2 mm/s and 30 seconds delay between first and second compression. Hardness (g_f), adhesiveness (g_f.s), springiness, cohesiveness, gumminess (g_f), chewiness (g_f) and resilience were calculated.

c) Color measurement

Color measurement was carried out on cake samples using the colorimeter with the light source of D65 to obtain the color values in the CIE color system. Measured values were L* (0-100; 0 is black, 100 is white), a* (+ is red, - is green), and b* (+ is yellow, - is blue).

d) Water activity (a_w)

Water activity of cake was determined by using water activity meter.

3.3.1.3 Statistical data analysis

a) Statistical analysis was performed using software SPSS 20.0 for windows version to calculate means values$\pm$SD. of physical properties measured for each sample. Analysis of variance (ANOVA) with Duncan's new multiple range test (DMRT) was applied. The level of significance used was 95% ($p\leq0.05$).

b) The pearson correlation coefficients among the physical properties (L*, a*, b*, water activity, specific volume, hardness, adhesiveness, springiness, cohesiveness, gumminess, chewiness and resilience) of butter cake was determined, using SPSS 20.0 for windows version.

c) The data of TPA (hardness, adhesiveness, cohesiveness, springiness, gumminess, chewiness and resilience) were analyzed by Principal component analysis (PCA) using XLstat in Microsoft excel for windows version.

d) The data of TPA (hardness, adhesiveness, springiness, cohesiveness, gumminess, chewiness and resilience) were analyzed by hierarchical cluster analysis based on the distance of integration. If the smallest distance means the experiment is in the same group. The analysis is based on the appropriate of the distance from the dendogram diagram. Defining distance or similarity properties of the cakes as a basis for clustering, using SPSS 20.0 for windows version.

3.3.2 Studying the relationship between the main ingredients and the properties of butter cakes

3.3.2.1 Experimental design

The central composite design (CCD) experiments were conducted to study the relationship between 4 main cake ingredients (sugar, butter, margarine and eggs) and the cake properties. The levels of studied factors were shown in Table 3.1. The 27 treatments with repeating at the center of 3 replications were conducted. The 27 cake formulations calculated from varying 5 levels of 4 factors were shown in Table 3.2. The experiment was repeated with 2 replications. The cake making process was shown in Figure 3.1. The amount of other ingredients fixed, included 100% cake flour, 60% evaporated milk, 2% salt, 4% baking powder, and 3% vanilla essence flavor (all ingredients are based on percent of flour weight).

Table 3.1 Code levels of sugar, butter, margarine and eggs used in cake formulation

Factors	Code level (% by flour weight)				
	-2	-1	0	1	2
Sugar (%)	100	110	120	130	140
Butter (%)	30	55	80	105	130
Margarine (%)	0	25	50	75	100
Eggs (%)	30	55	80	105	130

Ref. code: 25615409300216VXU

3.3.2.2 Analysis of physical properties of butter cakes

a) Specific volume: according to the experimental method in 3.3.1.2 a)

b) Texture profile analysis (TPA): according to the experimental method in 3.3.1.2 b)

c) Color measurement: according to the experimental method in 3.3.1.2 c)

d) Water activity (a_w): according to the experimental method in 3.3.1.2 d)

beat butter and sugar using kitchen aid mixer with a flat beater
at high speed about 10 minutes

↓

added eggs and mixed together using medium speed

↓

added flour, baking powder and salt to the mixture and switched with
evaporated milk after each dry ingredients addition
mixed together at low speed for 3 minutes

↓

pour batter to 2/3 of the cake pan sized 3.5x6x2 inch (230 g)

↓

baked at 180°C for 40 min

↓

removed cake from the pan and rest for 30 minutes on the rack

↓

stored in sealed plastic bag for 3 hours
at 25±2°C

Figure 3.1 Cake making process

Source: Jammek and Vinaikul (2003)

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Table 3.2 The level of factors from the CCD designed to study the relationship between the main ingredients and the properties of butter cakes

Trt	Studied factors (Code)				Studied factors (percent of weight flour)			
	Sugar	Butter	Margarine	Eggs	Sugar	Butter	Margarine	Eggs
E1	-1	-1	-1	-1	110	55	25	55
E2	1	-1	-1	-1	130	55	25	55
E3	-1	1	-1	-1	110	105	25	55
E4	1	1	-1	-1	130	105	25	55
E5	-1	-1	1	-1	110	55	75	55
E6	1	-1	1	-1	130	55	75	55
E7	-1	1	1	-1	110	105	75	55
E8	1	1	1	-1	130	105	75	55
E9	-1	-1	-1	1	110	55	25	105
E10	1	-1	-1	1	130	55	25	105
E11	-1	1	-1	1	110	105	25	105
E12	1	1	-1	1	130	105	25	105
E13	-1	-1	1	1	110	55	75	105
E14	1	-1	1	1	130	55	75	105
E15	-1	1	1	1	110	105	75	105
E16	1	1	1	1	130	105	75	105
E17	-2	0	0	0	100	80	50	80
E18	2	0	0	0	140	80	50	80
E19	0	-2	0	0	120	30	50	80
E20	0	2	0	0	120	130	50	80
E21	0	0	-2	0	120	80	0	80
E22	0	0	2	0	120	80	100	80
E23	0	0	0	-2	120	80	50	30
E24	0	0	0	2	120	80	50	130
E25	0	0	0	0	120	80	45	80
E26	0	0	0	0	120	80	45	80
E27	0	0	0	0	120	80	45	80

3.3.2.3 Statistical data analysis

a) Statistical analysis was performed using software SPSS 20.0 for windows version to calculate means values$\pm$SD. of physical properties measured for each sample. Analysis of variance (ANOVA) with Duncan's new multiple range test (DMRT) was applied. The level of significance used was 95% ($p \leq 0.05$).

b) The pearson correlation coefficients among the physical properties (L*, a*, b*, water activity, specific volume, hardness, adhesiveness, springiness, cohesiveness, gumminess, chewiness and resilience) of butter cake was determined, using SPSS 20.0 for windows version.

c) The data of TPA (hardness, adhesiveness, cohesiveness, springiness, gumminess, chewiness and resilience) were analyzed by Principal component analysis (PCA) using XLstat in Microsoft excel for windows version.

d) The data of TPA (hardness, adhesiveness, springiness, cohesiveness, gumminess, chewiness and resilience) were analyzed by response surface methodology (RSM), created contour plots to evaluate the change trend and the equation shows the relationship between the quality values and the studied factors, using Minitab 16.0 for windows version.

3.3.2.4 Cluster analysis

The data of TPA from studying the relationship between the main ingredients and the properties of butter cakes as well as the commercial cake were analyzed by Hierarchical cluster analysis based on the distance of integration. If the smallest distance means the experiment is in the same group. The analysis is based on the appropriate of the distance from the dendogram diagram. Defining distance or similarity properties of the cakes as a basis for clustering, using SPSS 20.0 for windows version. The middle formulation of each group from cluster analysis was selected as the group representative for the cake qualities.

a) Microstructure of cake

The cake representative from each group was selected from cluster analysis to study the cake microstructure using a Stereo microscope with a maginification of 8 and 32 times. The cake sample was prepared by slicing cake around the center with the size of 70x40x10 mm. according to the method of Turabi et al. (2010).

Ref. code: 25615409300216VXU

b) Image analysis of cake surface by using ImageJ

The microstructure images at 8 times magnification of each representative cake from each group were analyzed by using software ImageJ (http://imagej.nih.gov/ij). The pore area distribution, mean cell area and number or air cells per unit area were evaluated by following the method of Turabi et al. (2008) and Wilderjans et al. (2008).

c) Quantitative descriptive analysis (QDA)

The cake representative from each group was evaluated sensory qualities by QDA method, to develop vocabularies, definitions and evaluation methods in each attribute of butter cake. A panel of 10 assessors were selected, screened and recruited from the population of Thepsatri Rajabhat university, Lopburi province, Thailand whose age was 24-55 years old (Heenan et al., 2009). Assessors were trained according to the guideline of Heenan et al. (2009) and Heenan et al. (2010). The assessors were trained over 8 times with 2 hours duration for each training. For evaluation, the 40x40x20 mm cake sample was prepared with a 3-digit random code labeled on a plastic bag under white light at room temperature (25°C) and used a 15 cm line scale.

3.3.3 Studying the effect of storage temperature and time on the properties of butter cakes

3.3.3.1 Studied factors

The effect of storage temperature and time on the representative cake from each group was studied. The cake from each group was produced according to the process as shown in Fig 3.1 and each one was packed in plastic bag (Oriented polypropylene, OPP).The cake samples at 25$\pm$2°C were analyzed at 0, 2, 4, 6 days and cake samples at 4$\pm$2°C were analyzed at 0, 6, 12, 18 days. They were kept in a controlled temperature and relative humidity incubator throughout the experiment. The experiment was repeated with 2 replications. Factorial design in CRD was used for this experiment.

Ref. code: 25615409300216VXU

3.3.3.2 Analysis of physical properties of butter cakes

a) Texture profile analysis (TPA): according to the experimental method in 3.3.1.2 b)

b) Water activity (a_w): according to the experimental method in 3.3.1.2 d)

3.3.3.3 Analysis of thiobarbituric acid (TBA)

Lipid oxidation of stored butter cake at 4$\pm$2°C and 25$\pm$2°C for each storage time was evaluated according to AOAC (2000).

3.3.3.4 Analysis of retrogradation rate

Determined the retrogradation rate of the cake representative from each group at 4$\pm$2°C and 25$\pm$2°C for each storage time using DSC by following the method of Ji et al. (2007). The rate of retrogradation was calculated from the ratio of enthalpy changed of the retrogradation at times to the change in enthalpy of gelatinization, as shown in equation 3.2

$$\text{Retrogradation rate } (\theta) = \frac{H_t - H_0}{H_\infty - H_0} = \frac{\Delta H_{Retrogradation}}{\Delta H_{Gelatinization}} \quad \text{-------------- } 3.2$$

Where θ is rate of retrogradation

H_t is enthalpy at times of staling (t)

H_0 is enthalpy at zero day of staling (t=0)

H_∞ is enthalpy at the last day of staling (t=6 days at 25$\pm$2°C or t=18 days at 4$\pm$2°C)

3.3.3.5 Sensory evaluation

Sensory evaluation of the representative cake from each group stored at 4$\pm$2°C and 25$\pm$2°C for each storage time was performed using a 9-point Hedonic scale test of 50 people with the age between 24-55 years. Each panellist was asked to rate the liking of quality attributes according to appearance, color, flavor, taste and texture of each sample using a 9-point hedonic scale (1 = dislike extremely, 5 = neither dislike nor like, and 9 = like extremely).

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3.3.3.6 Microbiological properties

a) Total bacteria (AOAC, 2000); must be less than $1x10^6$ CFU/g (Thai industrial standard of cake, 2012).

b) *Stapphylococcus aureus* (AOAC, 2000); must be less than $1x10^1$ CFU/g (Thai industrial standard of cake, 2012).

c) *Bacillus cereus* (AOAC, 2000); must be less than $1x10^2$ CFU/g (Thai industrial standard of cake, 2012).

d) Yeast and mold (AOAC, 2000); must be less than $1x10^2$ CFU/g (Thai industrial standard of cake, 2012).

3.3.3.7 Statistic data analysis

a) Statistical analysis was performed using software SPSS 20.0 for windows version to calculate means values$\pm$SD. of physical, chemical and sensory properties. Analysis of variance (ANOVA) with Duncan's new multiple range test (DMRT) was applied. The level of significance used was 95% ($p\leq0.05$)

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CHAPTER 4
RESULTS AND DISCUSSION

4.1 Clustering of commercial butter cakes products

4.1.1 Sampling of commercial butter cakes products

Based on the market survey of commercial butter cake products which were available from department stores, convenience stores and bakery shops during January - February 2014 in Bangkok, Pathum Thani and Nonthaburi provinces, there were 12 commercial sliced butter cake products which were collected in the scope of this research. The information of the sampling cake products including the product name, brand, manufacturer, price and packaging is shown in Table 4.1.

The survey result showed that the price of sliced commercial butter cakes was between 11-55 bahts and they were mostly contained in the sealed plastic bag more than in the plastic box. For the chemical and physical properties such as the water activity, color, specific volume and texture property of the sampling cake products as well as the correlation among those properties including cluster analysis and the principal component analysis (PCA) were thereby analyzed in the next section.

Ref. code: 25615409300216VXU

Table 4.1 The market survey of commercial butter cake products

Sample	Product name	Brand	Manufacturer	Price (Bahts)	Packaging	Product image
C1	Butter cake	See Fah	See Fah Co., Ltd.	25	Plastic bag	
C2	Butter cake	Village bake'n cake	Village Food Service Co., Ltd.	20	Plastic box	
C3	Butter cake	Le Pan	CP Ram Co., Ltd.	18	Plastic bag	
C4	Butter cake	Bake @ dome	Bake @ dome bakery shop , Thammasat University	15	Plastic bag	

Ref. code: 25615409300216VXU

Table 4.1 The market survey of commercial butter cake products (cont.)

Sample	Product name	Brand	Manufacturer	Price (Bahts)	Packaging	Product image
C5	Butter vanilla cake	S and P	S and P Syndicate Co., Ltd.	24	Plastic bag	
C6	Butter cake	Mezzo	Mezzo Co., Ltd.	45	Plastic bag	
C7	Butter cake	Victory	Victory Bakery Chockchai 4	11	Plastic bag	
C8	Butter cake	Starbuck	Starbucks Coffee (Thailand) Co., Ltd.	55	Plastic bag	

Ref. code: 25615409300216VXU

Table 4.1 The market survey of commercial butter cake products (cont.)

Sample	Product name	Brand	Manufacturer	Price (Bahts)	Packaging	Product image
C9	Butter cake	Bow cake	Bow cake Homemade bakery shop	15	Plastic bag	
C10	Butter cake	Kudsan	Kudsan Bakery and Coffee shop	26	Plastic bag	
C11	Butter cake	Douji	Douji Bakery Co., Ltd.	15	Plastic bag	
C12	Butter cake slice	Foodland	Foodland supermarket Co., Ltd.	38	Plastic bag	

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4.1.2 Analysis of physical properties of commercial butter cakes

By measuring the chemical and physical properties of 12 products of commercial butter cakes as shown in Table 4.2 and 4.3, it was found that the properties of all sampling cake products (L*, a*, b*, water activity, specific volume, hardness, adhesiveness, springiness, cohesiveness, gumminess, chewiness and resilience) were significantly different ($p \leq 0.05$). The value of lightness (L*), red color (a*), and yellow color (b*) of all cakes were between 75.62-84.36, 2.33-6.64, and 32.25-39.38, respectively. The water activity of all cakes were between 0.87-0.92. The specific volume of all cakes were between 1.84-3.33 cm^3/g. For the L*, C5, C7 and C8 had the highest value of L*, but C12 had the lowest value of L*. C9 and C11 had the highest value of a*, but C7 had the lowest value of a*. C2, C7 and C11 had the highest value of b*, C3 had the lowest value of b*. C1, C4, C5, C7 and C8 had the highest value of water activity, but C2, C11 and C12 had the lowest value of water activity. C7 and C8 had the highest value of specific volume, but C3 had the lowest value of specific volume.

For the texture properties of commercial butter cakes, it was found that the hardness of all cakes were between 296.25-747.66 g_f. The adhesiveness value of all cakes were between 1.98-10.70 g_f.s. The springiness, cohesiveness, gumminess, chewiness and resilience of all cakes were between 0.77-0.92, 0.42-0.59, 138.52-295.69 g_f, 120.29-300.25 g_f and 0.11-0.30, respectively. C3, C4, C8, C10 and C11 had the highest value of hardness, but C6 had the lowest value of hardness. C1, C5, C6, C10 and C11 had the highest value of adhesiveness, but C4 had the lowest value of adhesiveness. C5, C7, C8, C9 and C11 had the highest value of springiness, but C6 had the lowest value of springiness. C5, C7, C9 and C11 had the highest value of cohesiveness, but C3, C4, C6 and C12 had the lowest value of cohesiveness. C1, C2, C5, and C11 had the highest value of gumminess, but C4 had the lowest value of gumminess. C1, C2 and C5 had the highest value of chewiness, but C3 had the lowest value of chewiness. C5, C7 and C9 had the highest value of resilience, but C1, C3, C4, C6 and C12 had the lowest value of resilience.

The data of chemical and physical properties of the sampling cakes were then analyzed by Pearson correlation coefficient as shown in Table 4.4 to find the relationship among the properties of commercial butter cakes. The result found that the L* of cake was positively correlated with water activity at 99% significant

Ref. code: 25615409300216VXU

level. Since water activity was related to the maillard reaction in that it was the reaction occurred well at low water activity, so the cake crumb would have high value of red color (a*) and low value of lightness (L*) (Mohamad et al., 2015). The b* of cake was positively correlated with specific volume and cohesiveness at 99% significant level, and positively correlated with springiness and resilience at 95% significant level. It could be because yellow color of cake crumbs were from the carotenoid pigment of the ingredients such as butter, margarine and eggs which was entrapped in the air cell during mixing (Conforti, 2016). Specific volume was positively correlated with resilience at 99% significant level, and also positively correlated with springiness and cohesiveness at 95% significant level. In addition, springiness was positively correlated to cohesiveness and resilience at 99% significant level. This indicated that cakes with high specific volume would have light texture with a lot of air cells inside the structure but the structure was so strong and elastic that the value of springiness, cohesiveness and resilience were rather high.

Table 4.2 L*, a*, b*, a_w and specific volume of commercial butter cakes

Sample	L*	a*	b*	a_w	Specific volume (cm^3/g)
C1	82.41 ± 0.35^{b}	4.74 ± 0.27^{b}	35.44 ± 0.55^{de}	0.92 ± 0.02^{a}	2.27 ± 0.10^{gh}
C2	80.40 ± 0.25^{d}	4.58 ± 0.27^{b}	39.17 ± 0.86^{a}	0.89 ± 0.01^{cde}	2.65 ± 0.08^{cd}
C3	80.34 ± 0.71^{d}	4.20 ± 0.21^{c}	32.25 ± 0.77^{f}	0.90 ± 0.02^{bcd}	1.84 ± 0.28^{i}
C4	81.48 ± 0.28^{c}	3.45 ± 0.10^{ef}	36.68 ± 0.44^{cd}	0.92 ± 0.01^{a}	2.60 ± 0.09^{de}
C5	84.28 ± 0.60^{a}	3.81 ± 0.15^{d}	38.34 ± 0.71^{ab}	0.92 ± 0.01^{a}	3.03 ± 0.12^{b}
C6	81.60 ± 0.29^{bc}	3.43 ± 0.05^{ef}	35.70 ± 0.33^{de}	0.88 ± 0.01^{e}	2.31 ± 0.16^{fgh}
C7	84.36 ± 0.22^{a}	2.33 ± 0.02^{g}	39.38 ± 0.28^{a}	0.92 ± 0.01^{a}	3.25 ± 0.10^{a}
C8	83.69 ± 0.41^{a}	3.72 ± 0.12^{de}	38.79 ± 0.69^{ab}	0.91 ± 0.01^{ab}	2.84 ± 0.13^{bc}
C9	77.33 ± 0.50^{f}	6.36 ± 0.10^{a}	37.79 ± 0.48^{bc}	0.87 ± 0.01^{e}	3.33 ± 0.08^{a}
C10	80.93 ± 0.54^{cd}	4.00 ± 0.05^{cd}	35.74 ± 0.05^{de}	0.90 ± 0.01^{bcd}	2.10 ± 0.08^{h}
C11	78.78 ± 0.10^{e}	6.64 ± 0.43^{a}	38.08 ± 0.98^{ab}	0.89 ± 0.01^{de}	2.40 ± 0.04^{efg}
C12	75.62 ± 0.36^{g}	3.24 ± 0.23^{f}	34.57 ± 0.55^{e}	0.89 ± 0.01^{de}	2.52 ± 0.01^{def}

Note: Mean values with different letters in each column are significantly different ($p \leq 0.05$) as determined by Duncan's new multiple range test (DMRT), and mean values±SD.

Ref. code: 25615409300216VXU

Table 4.3 Texture properties of commercial butter cakes

Sample	Hardness (g_f)	Adhesiveness (g_f.s)	Springiness (-)	Cohesiveness (-)	Gumminess (g_f)	Chewiness (g_f)	Resilience (-)
C1	383.89 ± 10.75^{c}	-10.70 ± 0.23^{a}	0.87 ± 0.03^{bc}	0.52 ± 0.01^{c}	286.68 ± 11.58^{a}	300.25 ± 12.67^{a}	0.16 ± 0.01^{bc}
C2	393.22 ± 15.69^{c}	-4.45 ± 0.76^{c}	0.89 ± 0.03^{b}	0.52 ± 0.01^{c}	294.86 ± 9.30^{a}	292.53 ± 10.92^{a}	0.17 ± 0.01^{b}
C3	747.66 ± 21.29^{a}	-5.63 ± 0.72^{b}	0.83 ± 0.04^{c}	0.44 ± 0.03^{d}	206.25 ± 15.27^{bc}	120.29 ± 8.51^{d}	0.14 ± 0.02^{c}
C4	662.92 ± 18.42^{a}	-1.98 ± 0.78^{d}	0.83 ± 0.01^{c}	0.46 ± 0.01^{d}	138.52 ± 7.32^{d}	163.36 ± 11.34^{c}	0.14 ± 0.01^{c}
C5	560.14 ± 24.78^{b}	-7.68 ± 0.61^{ab}	0.92 ± 0.01^{a}	0.59 ± 0.03^{a}	294.58 ± 8.37^{a}	294.17 ± 9.45^{a}	0.28 ± 0.01^{a}
C6	296.25 ± 27.85^{d}	-9.61 ± 0.48^{a}	0.77 ± 0.02^{d}	0.42 ± 0.01^{d}	251.06 ± 10.35^{b}	233.46 ± 10.24^{b}	0.11 ± 0.01^{c}
C7	377.98 ± 9.73^{c}	-4.71 ± 0.42^{c}	0.91 ± 0.03^{ab}	0.58 ± 0.02^{a}	193.89 ± 14.54^{bc}	159.03 ± 9.93^{c}	0.29 ± 0.01^{a}
C8	651.51 ± 12.59^{a}	-4.01 ± 0.59^{c}	0.90 ± 0.01^{ab}	0.55 ± 0.01^{b}	218.46 ± 17.34^{bc}	168.81 ± 8.13^{c}	0.18 ± 0.01^{b}
C9	564.85 ± 24.98^{b}	-5.98 ± 0.49^{b}	0.92 ± 0.01^{a}	0.59 ± 0.01^{a}	209.86 ± 13.12^{bc}	168.01 ± 14.88^{c}	0.30 ± 0.01^{a}
C10	644.93 ± 19.59^{ab}	-7.72 ± 0.64^{ab}	0.88 ± 0.01^{b}	0.51 ± 0.01^{c}	184.23 ± 19.56^{c}	224.87 ± 8.92^{b}	0.17 ± 0.01^{b}
C11	702.20 ± 11.82^{a}	-10.27 ± 0.59^{a}	0.91 ± 0.03^{ab}	0.58 ± 0.04^{a}	295.69 ± 9.94^{a}	233.44 ± 9.51^{b}	0.20 ± 0.01^{b}
C12	391.36 ± 26.95^{c}	-2.88 ± 0.71d	0.87 ± 0.03^{bc}	0.43 ± 0.01^{d}	195.37 ± 10.28^{c}	158.25 ± 12.83^{c}	0.14 ± 0.01^{c}

Note: Mean values with different letters in each column are significantly different ($p \leq 0.05$) as determined by Duncan's new multiple range test (DMRT), and mean values±SD.

Ref. code: 25615409300216VXU

Table 4.4 Pearson correlation between physical properties of commercial butter cakes

Parameter	L*	a*	b*	a_w	Specific volume	Hardness	Adhesiveness	Springiness	Cohesiveness	Gumminess	Chewiness	Resilience
L*	1	-0.469	0.370	**0.737****	0.171	-0.044	-0.132	0.034	0.296	0.130	0.273	0.198
a*	-0.469	1	0.079	-0.516	-0.027	0.364	-0.452	0.337	0.401	0.437	0.227	0.194
b*	0.370	0.079	1	0.123	**0.775****	-0.147	0.089	**0.627***	**0.759****	0.277	0.316	**0.617***
a_w	**0.737****	-0.516	0.123	1	0.042	0.108	0.126	0.134	0.158	-0.103	0.117	0.081
Specific volume	0.171	-0.027	**0.775****	0.042	1	-0.218	0.308	**0.615***	**0.673***	-0.016	-0.031	**0.817****
Hardness	-0.044	0.364	-0.147	0.108	-0.218	1	0.116	0.200	0.171	-0.260	-0.370	0.044
Adhesiveness	-0.132	-0.452	0.089	0.126	0.308	0.116	1	0.052	-0.206	**-0.660***	**-0.598***	-0.012
Springiness	0.034	0.337	**0.627***	0.134	**0.615***	0.200	0.052	1	**0.885****	0.243	0.152	**0.793****
Cohesiveness	0.296	0.401	**0.759****	0.158	**0.673***	0.171	-0.206	**0.885****	1	0.360	0.277	**0.871****
Gumminess	0.130	0.437	0.277	-0.103	-0.016	-0.260	**-0.660***	0.243	0.360	1	**0.798****	0.120
Chewiness	0.273	0.227	0.316	0.117	-0.031	-0.370	**-0.598***	0.152	0.277	**0.798****	1	0.031
Resilience	0.198	0.194	**0.617***	0.081	**0.817****	0.044	-0.012	**0.793****	**0.871****	0.120	0.031	1

Note: * indicated significantly different at $p \leq 0.05$ and ** indicated significantly different at $p \leq 0.01$.

Ref. code: 25615409300216VXU

4.1.3 Cluster analysis of commercial butter cakes

Based on the statistical analysis of the texture properties (TPA values) of 12 commercial butter cakes, there were significant differences ($p \leq 0.05$) among all of the cake products for each texture property such as hardness, adhesiveness, springiness, cohesiveness, gumminess, chewiness and resilience. In order to illustrate differences between the texture properties of commercial butter cakes based on texture profile analysis, PCA (principal component analysis) was carried out by using the average value of texture properties for each attribute to analyze the correlation among each other. By considering the factor loadings as shown in Table 4.5, the PCA described 75.89% of total variation on Principal component 1 and 2 (PC1 and PC2). As shown in Figure 4.1, PC1 (horizontal axis) which described the variation of 43.55% had a positive relationship with springiness, cohesiveness, gumminess and resilience. The PC2 (vertical axis) which describes the variance of 32.34% had a positive relationship with chewiness, and had a negative relationship with hardness and adhesiveness.

Table 4.5 Factor loading of the texture properties of commercial butter cakes

Texture properties	Factor loading	
	PC1	PC2
Hardness	-0.058	**-0.539**
Adhesiveness	-0.479	**-0.639**
Springiness	**0.783**	-0.532
Cohesiveness	**0.899**	-0.396
Gumminess	**0.693**	0.607
Chewiness	0.611	**0.679**
Resilience	**0.736**	-0.544

Note: Bold letter refers to the factor loadings which explained by the PC1 and PC2.

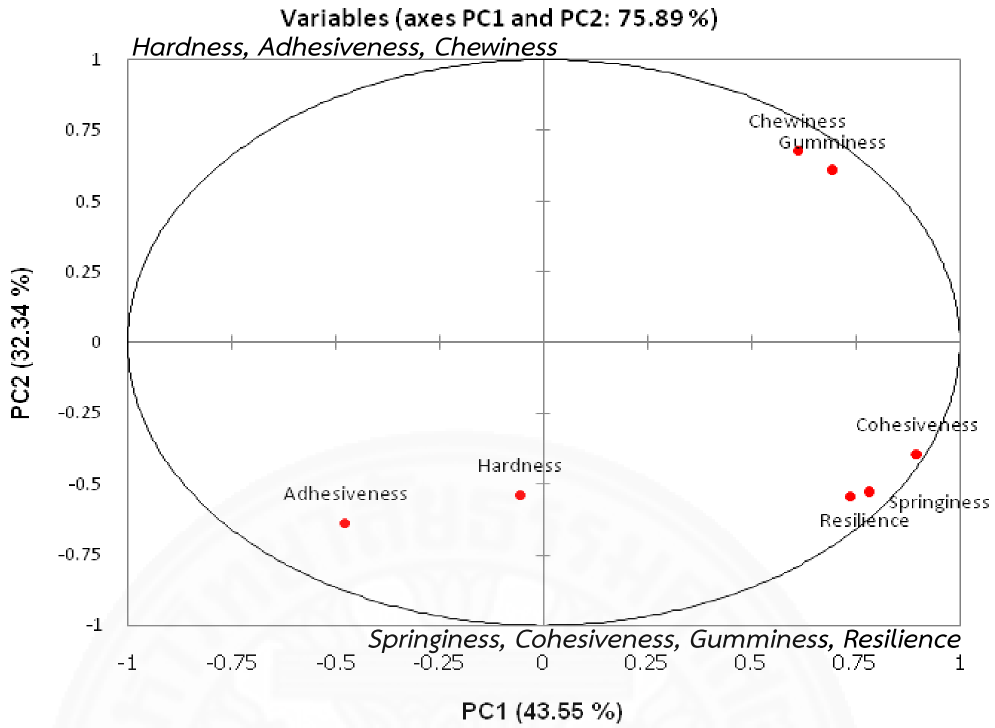

Figure 4.1 Loading plot graph of texture properties such as hardness, adhesiveness, springiness, cohesiveness, gumminess, chewiness and resilience of commercial butter cakes

The result of clustering the texture properties of commercial butter cakes by using Hierarchical cluster analysis method was shown in Figure 4.2. By considering the euclidean distance between the variables, the closet distance between measured variables would be placed in the same group. By evaluating the clustering of 12 commercial butter cakes using PCA technique and Hierarchical cluster analysis, the bi-plot of texture properties and commercial butter cakes was created as shown in Figure 4.3. The figure indicated that the 12 commercial butter cakes could be divided into 4 groups as following.

Group I : Cake with high springiness, cohesiveness and resilience but in low gumminess and chewiness (C7, C8, C9 and C10)

Group II : Cake with high springiness, cohesiveness, gumminess and chewiness (C1, C2, C5 and C11)

Group III : Cake with low springiness, cohesiveness, resilience, gumminess and chewiness but high in adhesiveness (C3, C4 and C12)

Group IV : Cake with low springiness, cohesiveness, resilience and adhesiveness (C6)

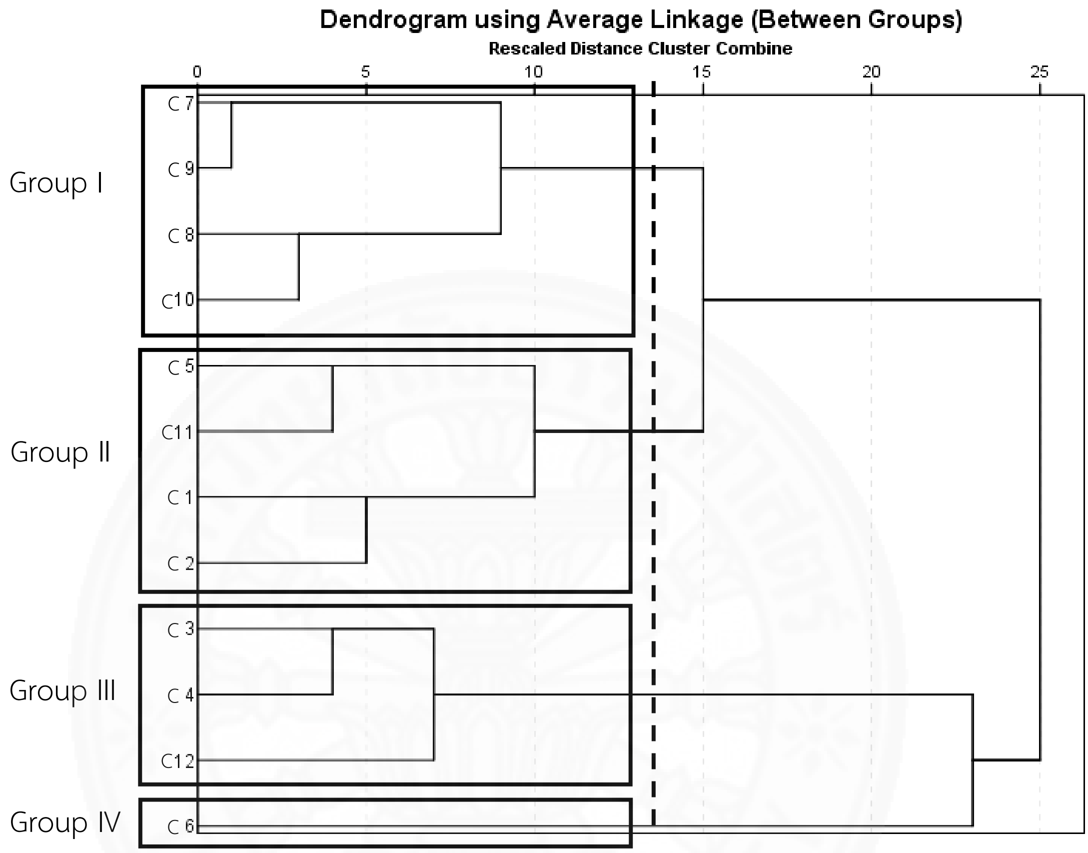

Figure 4.2 Dendrogram of hierarchical cluster analysis of the texture properties of 12 commercial butter cakes

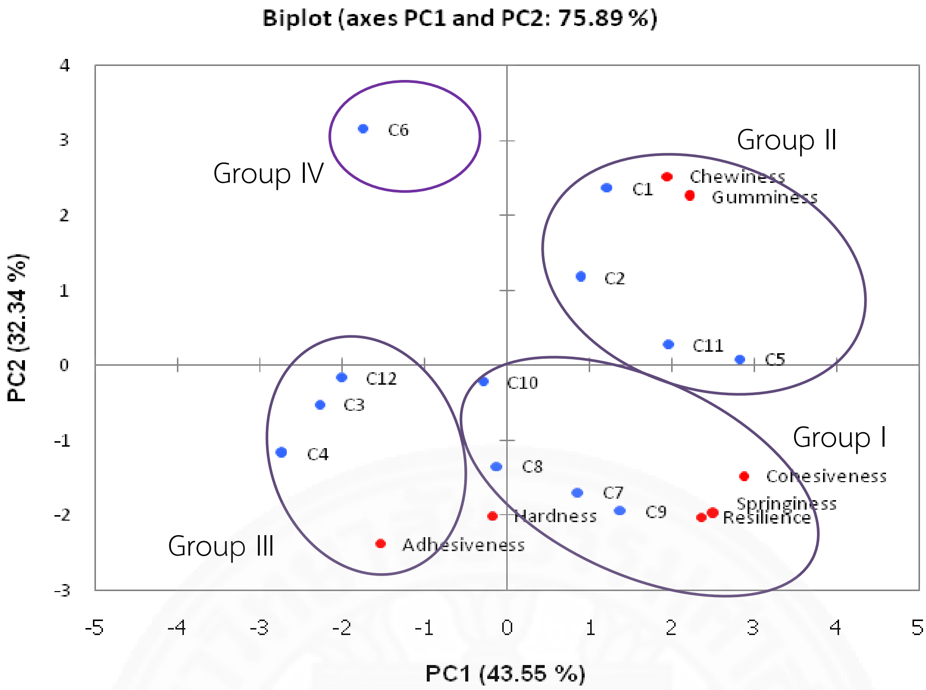

Figure 4.3 Bi-plot of texture properties and commercial butter cakes by PCA technique with the circle presenting different groups of commercial butter cakes

The group of commercial butter cakes could be described by the relationship diagram as shown in Figure 4.4.

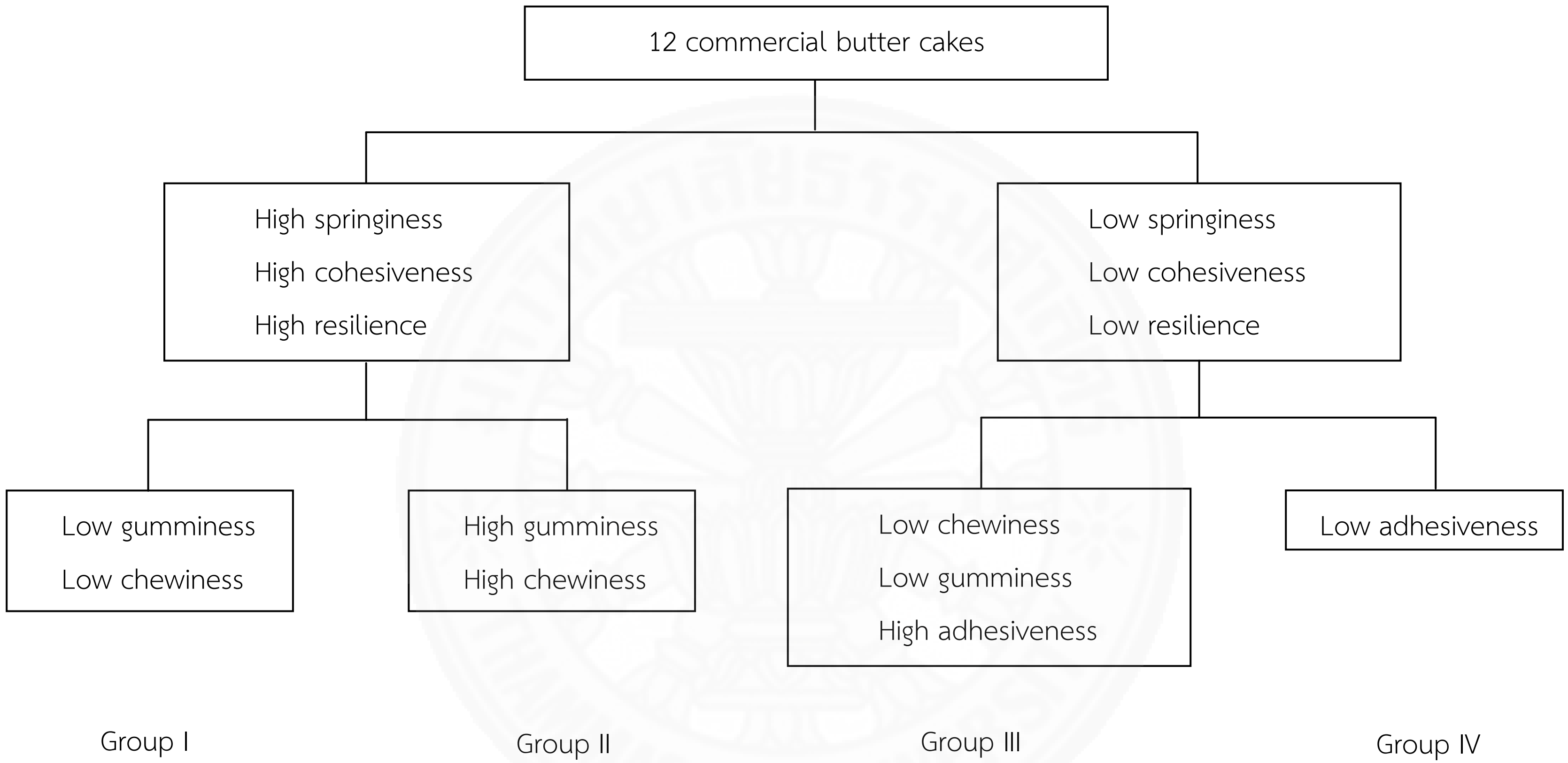

Figure 4.4 Group of commercial butter cake classified by texture properties using PCA and cluster analysis methods

Ref. code: 25615409300216VXU

4.2 Studying the relationship between the main ingredients and the properties of butter cakes

4.2.1 Analysis of physical properties of butter cakes

The physical properties of butter cakes made from varying 5 levels of 4 main cake ingredients (sugar, butter, margarine and eggs) using the central composite design (CCD) with 27 treatments were analyzed, the result of color (L*, a*, b*), water activity and specific volume of cake were shown in Table 4.6 and the texture properties from texture profile analysis were shown in Table 4.7. The result found that the physical properties of all cake samples (L*, a*, b*, water activity, specific volume, hardness, adhesiveness, springiness, cohesiveness, gumminess, chewiness and resilience) were significantly different ($p \leq 0.05$).

Considering the color of cakes, the result found that all cakes had the L*, a*, b* value between 66.80-73.51, 2.83-5.89 and 31.05-39.53, respectively. The butter cakes with low ratio of sugar, butter, margarine and egg showed low value of L*. The butter cake with high ratio of margarine and egg had high value of b*. Due to the fact that butter and egg has the natural pigment carotene, which is a source of vitamin A and give a yellow-orange color, which also make the cake look more yellow (Andersen and Williams, 1965; Pyler, 1988). Eggs also contain protein (and a small amount of glucose) that contributes to the brown color from maillard reactions (Paula, 2007). Moreover, margarine could give yellow color to cake because it was added yellow colorants to look same color as butter (Suraphat, 2009). The value of water activity of all cakes were between 0.84-0.92. The butter cakes with high ratio of egg had high value of water activity. Generally, the water activity of plain cake is between 0.80-0.90 and moist cake is between 0.90-0.95 (Cauvain and Young, 2006). The ingredients of cake have effected on water activity. Cakes that have a lot of liquid ingredients, such as water, milk, eggs, will cause the high moisture in cake. Egg white consists of water up to 88% (Wilderjans et al., 2013). But the butter cakes with high ratio of sugar had low value of water activity. Because sugar absorbed water in the system and resulted in decreasing of free water (Kim and Walkers, 1992). The values of specific volume of all cakes were between 1.16-2.97. It was found that butter cake with high ratio of egg showed high value of specific volume, it may be because egg proteins helped forming protein network and trapping the air cell in the cake structure which made the cake higher in volume (Pyler, 1988).

For the texture properties of butter cakes, it was found that hardness, springiness, cohesiveness, gumminess, chewiness and resilience of all cakes were between 247.33-706.14 g_f, 0.61-0.93, 0.48-0.67, 106.35-316.23 g_f, 78.65- 265.03 g_f and 0.16-0.33, respectively. It can be seen that there was a wide range of texture values for each attribute since the texture properties of cake related to the ratio of ingredients combination and their functionality. As seen in Table 4.7, cake made of high ratio of margarine and eggs showed low value of hardness, gumminess and chewiness which was due to the fact that margarine is manufactured from various hydrogenated animal and vegetable fats that are soft and have good creaming ability. Therefore it could help the batter incorporating the air cells while mixing, resulted in a soft texture and moist cake crumb (Pyler, 1988). In addition, margarine itself contained emulsifier from manufacturer which could also help improve the cake volume. However, using butter in a very high ratio in cake formulation could cause cake collapse and firm crumb. Because the fat distributed around the structure of the cake. During whipping, the fat entrapped the air cells and became to oil droplets dispersed around in aqueous phase of batter when baking (Wilderjans et al., 2013). Another main ingredient that affected the cake texture is sugar. Sugar helped to whip cream and eggs to be stable and volume up (Cauvain and Young, 2006). The last main ingredient that this research interested was eggs. Proteins in eggs formed protein network and incorporated the air cell inside the batter, which gave the cake structure and egg yolks also contain natural emulsifiers, which help produce smooth batters and contribute to volume and texture.

The main ingredient combination that affected the cake texture was sugar and egg. The high ratio of sugar resulted in low value of hardness and springiness of cake. Since sugar itself helped whipping cream and increased cake volume by incorporation of air into the fat during creaming, caused the crumb cake softness and good in recovery (Cauvain and Young, 2006). Similar result have been reported that sugar in the high-ratio cake formulation results in a good air incorporation leading to a more viscous and stable foam (Paton et al., 1981). Therefore the cake formula with the high ratio of sugar and eggs which contain natural emulsifier and proteins that help incorporating more air cells during mixing showed low value of hardness because of high porosity of cake after baking. The butter cake with high ratio of eggs showed low values of hardness but high value of springiness and cohesiveness because of more air cells in the structure from whipping property that causes low hardness but the strong protein network from egg protein coagulation during baking causes high viscoelastic property in cake structure that gave high value of springiness and cohesiveness (Cauvain and Young, 2006; Wilderjans et al., 2013). Moreover, the previous study showed adding egg increased the batter viscosity which prevented the loss of air and provide increase batter stability at room temperature (Hesso et al., 2015b; Wilderjans et al., 2008).

Ref. code: 25615409300216VXU

Table 4.6 L*, a*, b*, a_w and specific volume of butter cakes

Trt	Ingredient levels (Code)				L*	a*	b*	a_w	Specific volume (cm^3/g)
	X_1	X_2	X_3	X_4					
E1	-1	-1	-1	-1	71.54 ± 0.41^{cdefg}	4.43 ± 0.08^{efghi}	31.27 ± 0.82^{kl}	0.84 ± 0.01^{gh}	2.97 ± 0.01^{a}
E2	1	-1	-1	-1	73.44 ± 0.64^{ab}	4.93 ± 0.11^{cdefg}	33.53 ± 0.54^{ij}	0.86 ± 0.01^{ef}	1.98 ± 0.15^{fgh}
E3	-1	1	-1	-1	72.10 ± 0.73^{bcdef}	4.54 ± 0.35^{defgh}	33.86 ± 0.83^{hi}	0.88 ± 0.01^{cdef}	1.19 ± 0.01^{m}
E4	1	1	-1	-1	71.25 ± 0.63^{cdefgh}	4.13 ± 0.38^{hijk}	35.01 ± 0.08^{gh}	0.88 ± 0.01^{cdef}	1.73 ± 0.01^{ijk}
E5	-1	-1	1	-1	69.98 ± 0.29^{ghi}	5.07 ± 0.37^{bcd}	37.26 ± 0.17^{cde}	0.88 ± 0.01^{cdef}	1.65 ± 0.04^{jkl}
E6	1	-1	1	-1	70.48 ± 0.17^{fghi}	5.89 ± 0.21^{a}	38.68 ± 0.21^{abc}	0.88 ± 0.01^{cdef}	1.49 ± 0.01^{l}
E7	-1	1	1	-1	69.38 ± 0.50^{i}	4.56 ± 0.03^{defgh}	36.74 ± 0.47^{def}	0.87 ± 0.03^{def}	1.62 ± 0.02^{kl}
E8	1	1	1	-1	67.64 ± 0.78^{j}	4.60 ± 0.09^{defgh}	36.14 ± 0.25^{efg}	0.85 ± 0.01^{fg}	1.67 ± 0.02^{jkl}
E9	-1	-1	-1	1	69.42 ± 0.30^{i}	4.26 ± 0.01^{hijk}	32.15 ± 0.32^{jkl}	0.90 ± 0.01^{abcd}	2.33 ± 0.14^{cd}
E10	1	-1	-1	1	69.38 ± 0.78^{i}	3.76 ± 0.08^{jklmn}	31.05 ± 0.64^{l}	0.89 ± 0.01^{bcde}	2.73 ± 0.11^{ab}
E11	-1	1	-1	1	66.80 ± 0.28^{j}	4.32 ± 0.22^{ghij}	32.98 ± 0.97^{ij}	0.89 ± 0.02^{bcde}	2.02 ± 0.04^{efgh}
E12	1	1	-1	1	69.78 ± 0.29^{hi}	3.64 ± 0.09^{klmn}	32.93 ± 0.03^{ij}	0.89 ± 0.01^{bcde}	2.03 ± 0.06^{efgh}
E13	-1	-1	1	1	69.70 ± 0.08^{hi}	3.88 ± 0.26^{ijkl}	33.99 ± 0.11^{hi}	0.91 ± 0.01^{abc}	2.43 ± 0.21^{c}
E14	1	-1	1	1	72.44 ± 0.36^{abcd}	3.85 ± 0.08^{ijklm}	35.43 ± 0.06^{fg}	0.91 ± 0.01^{abc}	1.90 ± 0.06^{ghi}

Note: X_1 = sugar, X_2 = butter, X_3 = margarine and X_4 = eggs. Mean values with different letters in each column are significantly different ($p \leq 0.05$) as determined by Duncan's new multiple range test (DMRT), and mean values$\pm$SD.

Ref. code: 25615409300216VXU

Table 4.6 L*, a*, b*, a_w and specific volume of butter cakes (cont.)

Trt	Ingredient levels (Code)				L*	a*	b*	a_w	Specific volume (cm^3/g)
	X_1	X_2	X_3	X_4					
E15	-1	1	1	1	66.10 ± 0.62^{j}	4.43 ± 0.49^{efghi}	37.35 ± 0.24^{cde}	0.92 ± 0.01^{a}	1.53 ± 0.07^{kl}
E16	1	1	1	1	67.38 ± 0.47^{j}	5.01 ± 0.76^{cdef}	39.12 ± 0.13^{ab}	0.90 ± 0.01^{abcd}	1.90 ± 0.04^{ghi}
E17	-2	0	0	0	70.23 ± 0.25^{ghi}	4.39 ± 0.30^{fghij}	36.78 ± 0.06^{def}	0.90 ± 0.01^{abcd}	1.84 ± 0.01^{hij}
E18	2	0	0	0	70.91 ± 0.11^{defgh}	2.83 ± 0.08^{n}	32.63 ± 0.06^{ijk}	0.89 ± 0.01^{bcde}	2.15 ± 0.21^{def}
E19	0	-2	0	0	72.30 ± 0.03^{abcde}	3.24 ± 0.21^{mn}	33.31 ± 0.19^{ij}	0.88 ± 0.01^{cdef}	1.74 ± 0.06^{ijk}
E20	0	2	0	0	70.66 ± 0.74^{efgh}	4.42 ± 0.26^{efghi}	37.93 ± 0.57^{bcd}	0.90 ± 0.01^{abcd}	1.16 ± 0.01^{m}
E21	0	0	-2	0	72.39 ± 0.98^{abcd}	3.26 ± 0.17^{lmn}	32.57 ± 0.22^{ijk}	0.88 ± 0.01^{cdef}	2.17 ± 0.06^{def}
E22	0	0	2	0	72.20 ± 0.17^{abcde}	5.65 ± 0.38^{ab}	39.53 ± 0.23^{a}	0.90 ± 0.01^{abcd}	1.24 ± 0.06^{m}
E23	0	0	0	-2	73.86 ± 0.94^{a}	5.39 ± 0.19^{abc}	36.02 ± 0.18^{efg}	0.85 ± 0.01^{fg}	1.55 ± 0.06^{kl}
E24	0	0	0	2	72.17 ± 0.95^{bcde}	4.62 ± 0.33^{defgh}	37.59 ± 0.36^{cd}	0.91 ± 0.01^{abc}	2.12 ± 0.19^{defg}
E25	0	0	0	0	73.51 ± 0.40^{ab}	4.82 ± 0.13^{cdefg}	38.62 ± 0.25^{bc}	0.87 ± 0.03^{def}	2.10 ± 0.16^{efg}
E26	0	0	0	0	72.76 ± 0.28^{abc}	4.83 ± 0.17^{cdefg}	38.82 ± 0.18^{bc}	0.89 ± 0.01^{bcde}	2.13 ± 0.04^{def}
E27	0	0	0	0	73.26 ± 0.29^{ab}	4.77 ± 0.02^{cdefgh}	38.90 ± 0.49^{bc}	0.90 ± 0.01^{abcd}	2.14 ± 0.01^{def}

Note: X_1 = sugar, X_2 = butter, X_3 = margarine and X_4 = eggs. Mean values with different letters in each column are significantly different ($p \leq 0.05$) as determined by Duncan's new multiple range test (DMRT), and mean values±SD.

Ref. code: 25615409300216VXU

Table 4.7 Texture properties of butter cakes

Trt	Ingredient levels(Code)				Hardness (g_f)	Adhesiveness (g_f.s)	Springiness (-)	Cohesiveness (-)	Gumminess (g_f)	Chewiness (g_f)	Resilience (-)
	X_1	X_2	X_3	X_4							
E1	-1	-1	-1	-1	391.87±11.23^{fg}	-3.38±0.38^{ghij}	0.83±0.03^{fg}	0.57±0.01^{bcde}	223.29±9.56^{efg}	185.68±13.92^{de}	0.25 ±0.01^{cd}
E2	1	-1	-1	-1	247.33±22.53^{p}	-4.80±0.93^{efghi}	0.84±0.02^{defg}	0.49±0.02^{efghij}	121.08±16.61^{no}	101.70±12.06^{kl}	0.19±0.01^{fghijk}
E3	-1	1	-1	-1	354.81±19.05^{hijk}	-4.54±0.82^{efghi}	0.71±0.01^{ijk}	0.52±0.02^{cdefgh}	185.91±17.13^{hij}	131.97±18.96^{ij}	0.23±0.01^{defg}
E4	1	1	-1	-1	361.89±12.99^{hij}	-11.49±0.96^{a}	0.69±0.01^{jkl}	0.47±0.07^{ghij}	169.76±18.36^{ijklm}	117.77±13.10^{jk}	0.19±0.03^{ghijk}
E5	-1	-1	1	-1	551.80±2.29^{c}	-9.63±0.83^{abc}	0.65±0.06^{lm}	0.46±0.05^{hij}	252.87±10.44^{cde}	163.77±3.92^{efg}	0.18±0.02^{hijkl}
E6	1	-1	1	-1	653.07±23.92^{b}	-9.81±0.53^{ab}	0.69±0.02^{jkl}	0.44±0.05^{hij}	289.01±15.06^{ab}	198.67±15.90^{d}	0.17±0.01^{ijkl}
E7	-1	1	1	-1	706.14±15.88^{a}	-7.82±0.35^{bcde}	0.70±0.03^{ijkl}	0.46±0.03^{hij}	316.23±6.10^{a}	222.03±14.97^{bc}	0.16±0.01^{kl}
E8	1	1	1	-1	446.04±5.88^{de}	-6.17±0.95^{cdefg}	0.67±0.05^{kl}	0.41±0.01^{j}	184.92±3.99^{hij}	124.14±11.03^{jk}	0.16±0.01^{kl}
E9	-1	-1	-1	1	431.72±20.93^{def}	-2.43±0.1^{hij}	0.93±0.01^{a}	0.66±0.03^{a}	284.25±0.51^{abc}	265.03 ±7.27^{a}	0.32±0.02^{a}
E10	1	-1	-1	1	327.95±2.67^{jklm}	-0.01±0.01^{j}	0.92±0.01^{a}	0.60±0.01^{abc}	201.65±1.42^{ghi}	185.59±5.72^{de}	0.28±0.01^{bc}
E11	-1	1	-1	1	343.78±3.21^{ijkl}	-5.90±0.20^{defgh}	0.87±0.01^{bcdef}	0.54±0.02^{cdefg}	186.03±5.70^{hij}	160.93±5.89^{fg}	0.21±0.01^{efgh}
E12	1	1	-1	1	266.63±0.13^{op}	-4.08±0.38^{fghi}	0.89±0.01^{abcd}	0.58±0.02^{bcd}	153.60±4.26^{jklmn}	137.27±4.19^{hij}	0.25±0.01^{cde}
E13	-1	-1	1	1	463.41±7.36^{dc}	-7.50±0.34^{bcdef}	0.86±0.01^{cdef}	0.55±0.01^{bcdefg}	272.17±13.31^{bcd}	234.33±8.60^{b}	0.22±0.01^{efgh}
E14	1	-1	1	1	412.48±5.12^{ef}	-7.42±1.51^{bcdef}	0.85±0.01^{defg}	0.52±0.01^{defgh}	212.99±3.49^{fgh}	180.49±6.11^{def}	0.20±0.01^{fghij}

Note: X_1 = sugar, X_2 = butter, X_3 = margarine and X_4 = eggs. Mean values with different letters in each column are significantly different ($p \leq 0.05$) as determined by Duncan's new multiple range test (DMRT), and mean values±SD.

Ref. code: 25615409300216VXU

Table 4.7 Texture properties of butter cakes (cont.)

Trt	Ingredient levels(Code)				Hardness (g_f)	Adhesiveness (g_f.s)	Springiness (-)	Cohesiveness (-)	Gumminess (g_f)	Chewiness (g_f)	Resilience (-)
	X_1	X_2	X_3	X_4							
E15	-1	1	1	1	318.03±2.14^{klmn}	-7.19±0.68^{bcdef}	0.79±0.01^{gh}	0.45±0.01^{hij}	143.66±1.40^{lmn}	114.14±3.25^{jkl}	0.17±0.01^{jkl}
E16	1	1	1	1	303.07±0.03^{lmno}	-4.05±0.96^{fghi}	0.80±0.01^{gh}	0.51±0.02^{defghi}	155.15±3.96^{jklmn}	124.37±6.18^{jk}	0.21±0.01^{fghi}
E17	-2	0	0	0	325.86±6.95^{jklm}	-9.48±1.23^{abcd}	0.83±0.02^{efg}	0.56±0.04^{bcdef}	182.66±7.73^{hijk}	152.10±8.08^{ghi}	0.23±0.03^{def}
E18	2	0	0	0	263.15±2.60^{op}	-4.60±0.30^{efghi}	0.84±0.01^{defg}	0.48±0.03^{fghij}	125.89±6.40^{no}	105.67±6.57^{kl}	0.20±0.01^{fghijk}
E19	0	-2	0	0	326.65±4.99^{jklm}	-5.03±1.88^{efghi}	0.91±0.01^{abc}	0.57±0.01^{bcde}	185.32±10.53^{chij}	168.48±9.54^{efg}	0.25±0.01^{cd}
E20	0	2	0	0	262.65±5.30^{op}	-6.77±0.23^{bcdefg}	0.74±0.02^{ij}	0.43±0.02^{ih}	106.35±6.31^{o}	78.65±2.79^{m}	0.17±0.01^{jkl}
E21	0	0	-2	0	252.89±8.71^{p}	-6.27±0.89^{bcdefgh}	0.92±0.01^{ab}	0.67±0.01^{a}	170.41±7.57^{ijkl}	156.23±7.04^{gh}	0.33±0.01^{a}
E22	0	0	2	0	473.16±9.93^{d}	-5.28±0.78^{efghi}	0.75±0.01^{hi}	0.48±0.08^{fghij}	241.73±14.30^{def}	201.25±0.93^{cd}	0.21±0.03^{efgh}
E23	0	0	0	-2	377.95±5.36^{ghi}	-0.46±0.03^{j}	0.61±0.03^{m}	0.43±0.08^{jh}	162.99±12.87^{jklm}	92.69±0.20^{lm}	0.17±0.03^{ijkl}
E24	0	0	0	2	385.58±3.49^{ghi}	-2.27±0.60^{ij}	0.89±0.01^{abcde}	0.63±0.01^{ab}	257.63±17.28^{bcd}	228.95±14.05^{b}	0.28±0.01^{b}
E25	0	0	0	0	269.51±1.07^{op}	-6.48±0.63^{bcdefg}	0.85±0.02^{defg}	0.50±0.01^{defghij}	133.86±3.17^{mno}	113.58±0.52^{jkl}	0.19±0.01^{fghijk}
E26	0	0	0	0	283.12±13.75^{nop}	-6.26±0.52^{bcdefg}	0.84±0.02^{defg}	0.48±0.01^{fghij}	135.25±3.94^{mno}	113.26±5.60^{jkl}	0.19±0.01^{fghijk}
E27	0	0	0	0	288.09±4.67^{mnop}	-6.42±0.71^{bcdefg}	0.85±0.02^{defg}	0.50±0.02^{defghij}	137.36±11.90^{mno}	114.86±9.02^{jkl}	0.20±0.01^{fghijk}

Note: X_1 = sugar, X_2 = butter, X_3 = margarine and X_4 = eggs. Mean values with different letters in each column are significantly different ($p \leq 0.05$) as determined by Duncan's new multiple range test (DMRT), and mean values±SD.

Ref. code: 25615409300216VXU

In order to understand the relationship between the cake properties, all of the physical properties in Table 4.6 and 4.7 were analyzed by Pearson correlation and the result is shown in Table 4.8. It can be seen that the L* of cake was positively correlated with specific volume, gumminess and chewiness at 99% significant level and L* of cake was positively correlated with water activity, hardness and springiness at 95% significant level. It was found that cakes with high value of water activity had the high value of lightness (L*) because water activity was related to the maillard reaction in that it was the reaction occurred well at low water activity, so the cake crumb would have low value of lightness (L*) (Mohamad et al., 2015). Moreover, that cakes with high value of lightness (L*) were made from high ratio of margarine and eggs, and also had the high value of specific volume, hardness, springiness gumminess and chewiness. Because margarine were to envelope the air cells while mixing which made cake high volume and eggs were formed structure and trap the air cell, so that the cake would have high value of specific volume, springiness gumminess and chewiness (Pyler, 1988). The a* of cake was positively correlated with b* and springiness at 95% significant level. The a_w of cake was positively correlated with springiness at 95% significant level. Since the cakes with high value of water activity were made from high ratio of butter and margarine which gave the cake have soft texture and good structure of crumb cake, so the cake would have high value of springiness. The specific volume was positively correlated with springiness and cohesiveness at 99% significant level, and specific volume was positively correlated with gumminess, chewiness and resilience at 95% significant level. Hardness of cake was positively correlated with gumminess at 95% significant level. Springiness was positively correlated with cohesiveness and resilience at 99% significant level, and springiness of cake was positively correlated with chewiness at 95% significant level. Cohesiveness was positively correlated with resilience at 99% significant level. Gumminess was positively correlated with chewiness at 99% significant level. In conclusion, specific volume is directly related to most of texture properties such as hardness, gumminess, chewiness, springiness and resilience.

Ref. code: 25615409300216VXU

Table 4.8 Pearson correlation between physical properties of butter cakes

Parameter	L*	a*	b*	a_w	Specific volume	Hard ness	Adhesive ness	Springi- ness	Cohesive ness	Gummi- ness	Chewi- ness	Resilience
L*	1	-0.178	0.280	**0.333***	**0.556****	**0.399***	-0.070	**0.357***	0.053	**0.467****	**0.512****	-0.143
a*	-0.178	1	**0.391***	-0.282	-0.242	0.297	-0.226	**-0.316***	-0.121	0.062	-0.015	-0.097
b*	0.280	**0.391***	1	0.313	-0.012	0.227	-0.265	-0.174	-0.232	0.197	0.180	-0.216
a_w	**0.333***	-0.282	0.313	1	0.153	0.132	-0.087	**0.431****	0.201	0.205	0.312	0.053
Specific volume	**0.556****	-0.242	-0.012	0.153	1	0.136	0.225	**0.689****	**0.496****	**0.319***	**0.400***	**0.367***
Hardness	**0.399***	0.297	0.227	0.132	0.136	1	-0.167	-0.067	-0.102	**0.322***	0.235	-0.224
Adhesiveness	-0.070	-0.226	-0.265	-0.087	0.225	-0.167	1	0.215	0.217	-0.292	-0.202	0.288
Springiness	**0.357***	**-0.316***	-0.174	**0.431****	**0.689****	-0.067	0.215	1	**0.736****	0.144	**0.317***	**0.523****
Cohesiveness	0.053	-0.121	-0.232	0.201	**0.496****	-0.102	0.217	**0.736****	1	0.155	0.261	**0.894****
Gumminess	**0.467****	0.062	0.197	0.205	**0.319***	**0.322***	-0.292	0.144	0.155	1	**0.949****	0.021
Chewiness	**0.512****	-0.015	0.180	0.312	**0.400***	0.235	-0.202	**0.317***	0.261	**0.949****	1	0.087
Resilience	-0.143	-0.097	-0.216	0.053	**0.367***	-0.224	0.288	**0.523****	**0.894****	0.021	0.087	1

Note: * indicated significantly different at $p \leq 0.05$ and ** indicated significantly different at $p \leq 0.01$.

Ref. code: 25615409300216VXU

4.2.2 Studying the regression model showing the relationship between texture properties of butter cakes and ingredients combination

The relationship between texture properties (TPA values) and the ratio of four main cake ingredients combination (sugar, butter, margarine and eggs) were analyzed by RSM and the regression equation of full quadratic model was created as shown in Table 4.9. The R-square values of hardness, adhesiveness, springiness, cohesiveness, gumminess, chewiness and resilience were 0.75, 0.69, 0.95, 0.94, 0.74, 0.79 and 0.92, respectively. It can be seen that most R-square values of all texture properties were equal or greater than 0.75 except for the adhesiveness value. The models for hardness, adhesiveness, springiness, cohesiveness, gumminess, chewiness and resilience could be explained at 75%, 69%, 95%, 94%, 74%, 79% and 92%, respectively. The regression equation could explain the best relationship of the main ingredients on springiness and cohesiveness (R^2=0.95 and 0.94, respectively). Table 4.10 showed the p-value of texture properties in regression coefficients of butter cake indicating the effect of single ingredient and interaction between some ingredients on texture properties. It can be seen that sugar had effect on cohesiveness, gumminess, and chewiness. Butter had effected on springiness, cohesiveness, gumminess, chewiness and resilience. Margarine had effected on hardness, springiness, cohesiveness, chewiness and resilience. Egg had effected on springiness, cohesiveness, chewiness and resilience. The square of margarine had effected on cohesiveness, gumminess, chewiness and resilience. The square of egg had effected on adhesiveness, springiness and gumminess. The interaction of sugar and butter, and sugar and egg had effected on cohesiveness. The interaction of butter and margarine had effected on adhesiveness and springiness.

Table 4.9 Regression model of texture properties and ingredients combination of butter cakes

Texture profile (Y_i)	Regression model	R^2
Hardness	$280.239 - 27.855X_1 - 21.135X_2 + 65.359X_3 - 34.609X_4$	0.75
	$+ 16.528X_1^2 + 16.563X_2^2 + 33.657X_3^2 + 38.341X_4^2 - 9.199X_1X_2$	
	$+ 5.854X_1X_3 + 3.093X_1X_4 - 14.733X_2X_3 - 26.805X_2X_4 - 54.640X_3X_4$	
Adhesiveness	$-6.721 + 0.430X_1 – 0.405X_2 – 0.874X_3 + 0.644X_4$	0.69
	$– 0.245X_1^2 + 0.040X_2^2 + 0.071X_3^2 + 1.173X_4^2 – 0.078X_1X_2$	
	$+ 0.552X_1X_3 + 0.898X_1X_4 + 1.533X_2X_3 – 0.092X_2X_4 – 0.283X_3X_4$	
Springiness	$0.844 + 0.001X_1 – 0.032X_2 – 0.041X_3 + 0.071X_4$	0.95
	$– 0.005X_1^2 - 0.008X_2^2 – 0.005X_3^2 – 0.027X_4^2 – 0.002X_1X_2$	
	$- 0.001X_1X_3 + 0.001X_1X_4 + 0.018X_2X_3 + 0.002X_2X_4 + 0.003X_3X_4$	
Cohesiveness	$0.495 – 0.014X_1 – 0.026X_2 – 0.042X_3 + 0.041X_4$	0.94
	$+ 0.003X_1^2 – 0.002X_2^2 + 0.017X_3^2 + 0.006X_4^2 + 0.012X_1X_2$	
	$+ 0.008X_1X_3 + 0.012X_1X_4 + 0.005X_2X_3 – 0.009X_2X_4 – 0.004X_3X_4$	
Gumminess	$138.825 – 20.408X_1 - 21.666X_2 + 18.503X_3 + 2.321X_4$	0.74
	$+ 8.932X_1^2 + 6.821X_2^2 + 21.880X_3^2 + 22.940X_4^2 + 2.465X_1X_2$	
	$+ 5.659X_1X_3 + 3.174X_1X_4 – 5.756X_2X_3 – 18.948X_2X_4 - 24.033X_3 X_4$	
Chewiness	$117.232 – 16.697X_1 – 23.430X_2 + 6.918X_3 + 17.873X_4$	0.79
	$+ 5.827X_1^2 + 4.478X_2^2 + 18.292X_3^2 + 13.812X_4^2 + 3.553X_1X_2$	
	$+ 5.916X_1X_3 + 0.903X_1X_4 – 0.157X_2X_3 – 17.177X_2X_4 - 16.687X_3X_4$	
Resilience	$0.194 – 0.007X_1 – 0.017X_2 – 0.028X_3 + 0.022X_4$	0.92
	$+ 0.001X_1^2 + 0.001X_2^2 + 0.016X_3 + 0.005X_4^2 + 0.009X_1X_2$	
	$+ 0.007X_1X_3 + 0.008X_1X_4 + 0.005X_2X_3 – 0.007X_2X_4 – 0.005X_3X_4$	

Note: Y_i = Texture profile data, X_1 = sugar, X_2 = butter, X_3 = margarine, X_4 = egg.
R^2 = Coefficient of determination.

Table 4.10 p-value of texture properties in regression coefficients of ingredients combination in butter cakes

Parameters	Hardness	Adhesiveness	Springiness	Cohesiveness	Gumminess	Chewiness	Resilience
Constant	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**
X_1	0.142	0.370	0.863	0.013*	0.037*	0.028*	0.099
X_2	0.256	0.398	0.000**	0.000**	0.028*	0.004**	0.001**
X_3	0.003**	0.083	0.000**	0.000**	0.055	0.320	0.000**
X_4	0.75	0.189	0.000**	0.000**	0.794	0.020*	0.000**
X_1^2	0.397	0.626	0.455	0.551	0.352	0.426	0.746
X_2^2	0.396	0.936	0.256	0.744	0.474	0.537	0.947
X_3^2	0.099	0.888	0.455	0.006**	0.035*	0.024*	0.002**
X_4^2	0.064	0.034*	0.001**	0.279	0.029*	0.075	0.206

Note: X_1 = sugar, X_2 = butter, X_3 = margarine and X_4 = eggs.

* indicated significantly different at $p \leq 0.05$ and ** indicated significantly different at $p \leq 0.01$.

Ref. code: 25615409300216VXU

Table 4.10 p-value of texture properties in regression coefficients of ingredients combination in butter cakes (cont.)

Parameters	Hardness	Adhesiveness	Springiness	Cohesiveness	Gumminess	Chewiness	Resilience
X_1X_2	0.679	0.893	0.801	**0.046***	0.821	0.671	0.065
X_1X_3	0.792	0.349	0.897	0.221	0.605	0.483	0.161
X_1X_4	0.889	0.139	0.909	**0.045***	0.771	0.914	0.106
X_2X_3	0.510	0.019*	**0.033***	0.469	0.599	0.985	0.291
X_2X_4	0.241	0.874	0.833	0.152	0.101	0.057	0.133
X_3X_4	0.027*	0.627	0.656	0.499	0.044*	0.064	0.338
R^2	0.75	0.69	**0.95**	**0.94**	0.74	0.79	0.92

Note: X_1 = sugar, X_2 = butter, X_3 = margarine and X_4 = eggs.

* indicated significantly different at $p \leq 0.05$ and ** indicated significantly different at $p \leq 0.01$.

Bold letter refers to the texture properties which had interaction of ingredients and had R^2 value more than 90%

Ref. code: 25615409300216VXU

The contour plot graph of ingredients that had interaction each other (butter and margarine on springiness, sugar and butter on cohesiveness and sugar and eggs on cohesiveness) and had the R-square value greater than 0.9 was created as shown in Figure 4.5-4.7. It was found that high ratio of butter and margarine resulted in low value of springiness. In addition, the combination of high ratio of butter and margarine led to low value of springiness because butter and margarine had good creaming ability that it can incorporating air cells during mixing and also contributed great and soft crumb cake (Pyler, 1988) resulted in low value of springiness as shown in Figure 4.5.

As seen in Figure 4.6, the high ratio of sugar and butter gave rise to the low value of cohesiveness. The combination of high sugar and butter ratio caused the low value of cohesiveness due to the fact that sugar and butter were performed creamy batter and entrapped air cell during mixing (Conforti, 2006) which led to low value of cohesiveness.

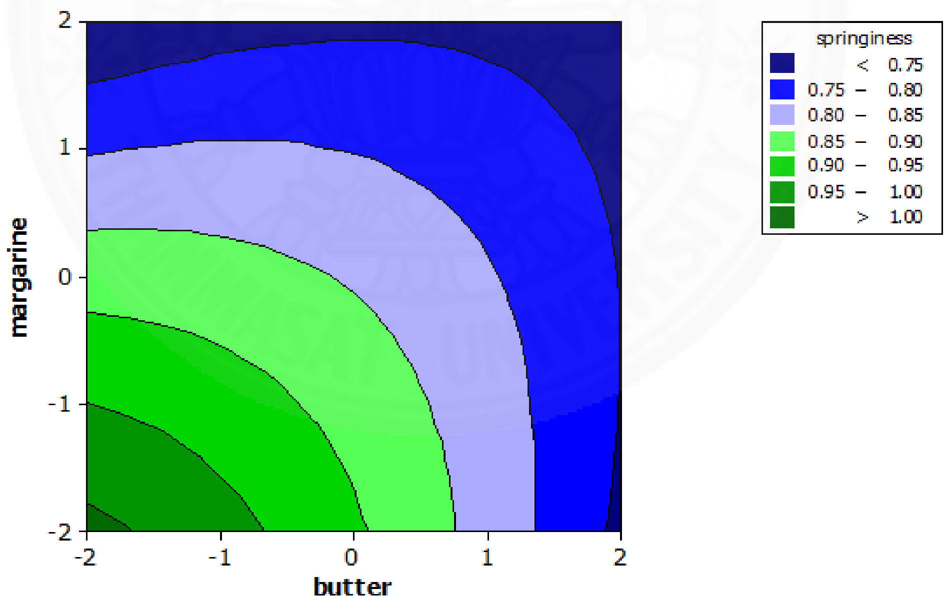

Figure 4.5 Contour plot of the effect of butter and margarine on springiness of butter cakes

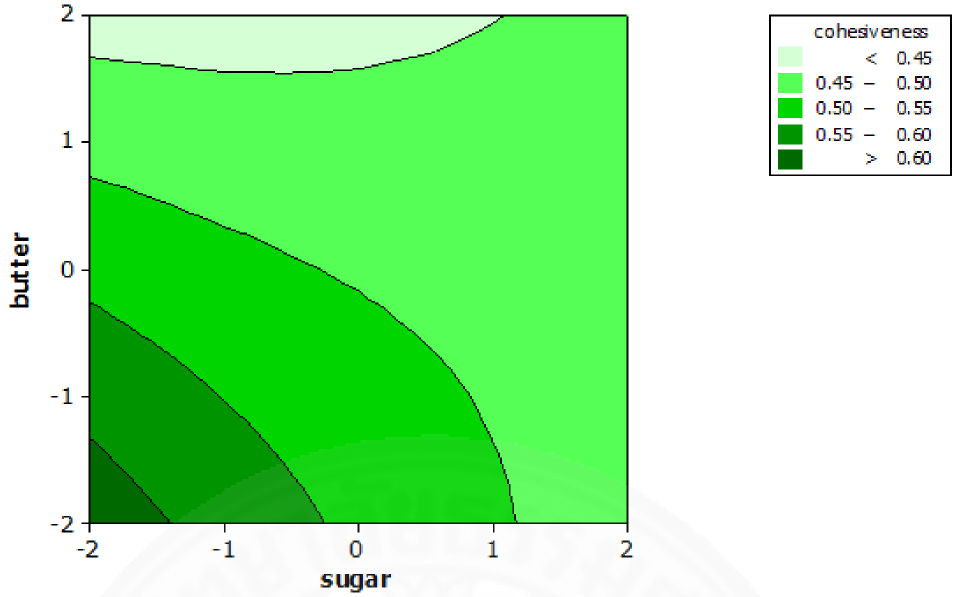

Figure 4.6 Contour plot of the effect of sugar and butter on cohesiveness of butter cakes

Moreover, the high ratio of sugar resulted in low value of cohesiveness but high ratio of egg led to high value of cohesiveness. This is due to the fact that protein in egg yolk acted as an emulsifying agent that caused the batter is more stable and formed protein network and trapped the air cell during mixing (Pyler, 1988; Wilderjans et al., 2013). Furthermore, it was found that the combination of high sugar and egg ratio caused high value of cohesiveness. When the eggs were mixed in the mixture, sugar was bound to the protein structure, making the fine structure of the cake (Wilderjans et al., 2013), which caused high value of cohesiveness as shown in Figure 4.7.

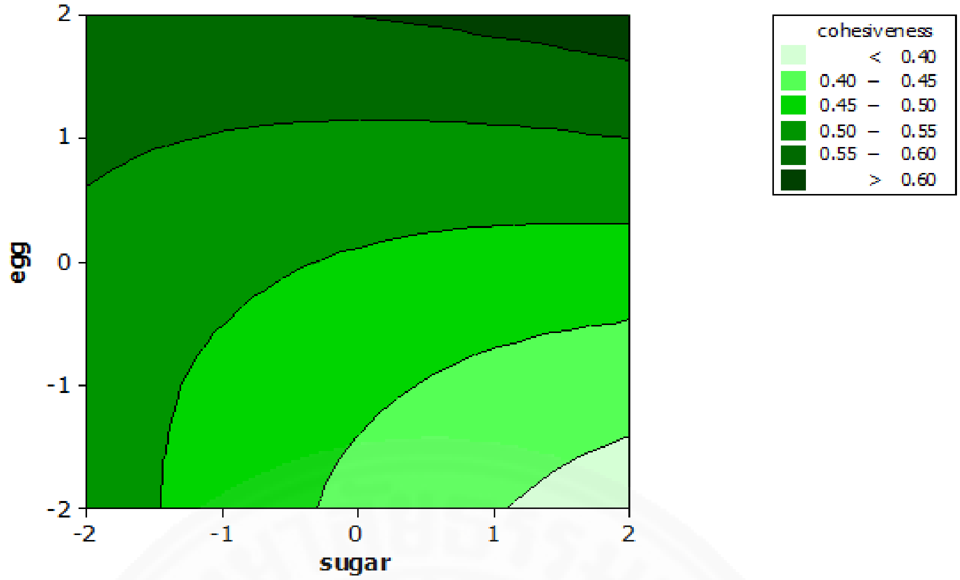

Figure 4.7 Contour plot of the effect of sugar and egg on cohesiveness of butter cakes

4.2.3 Cluster analysis of experimental butter cakes and commercial butter cakes

Based on the statistical analysis of the texture properties (TPA values) of 27 experimental butter cakes and 12 commercial butter cakes, there were significant differences ($p \leq 0.05$) among all of the cake products for each texture property. In order to illustrate differences between the texture properties of commercial and experimental butter cakes based on texture profile analysis, PCA was carried out by using the average value of texture properties for each attribute to analyze the correlation among each other. By considering the factor loadings as shown in Table 4.11, the PCA described 72.21% of total variation on Principal component 1 and 2 (PC1 and PC2). As shown in Figure 4.8, PC1 (horizontal axis) which described the variation of 40.34% had a positive relationship with springiness, cohesiveness, chewiness and resilience. The PC2 (vertical axis) which describes the variance of 31.87% had a positive relationship with hardness and gumminess, and had a negative relationship with adhesiveness.

Table 4.11 Factor loading of the texture properties of experimental butter cakes and commercial butter cakes

Texture properties	Factor loading	
	PC1	PC2
Hardness	0.119	**0.737**
Adhesiveness	0.167	**-0.563**
Springiness	**0.769**	-0.270
Cohesiveness	**0.917**	-0.305
Gumminess	0.531	**0.782**
Chewiness	**0.687**	0.623
Resilience	**0.772**	-0.451

Note: Bold letter refers to the factor loadings which explained by the PC1 and PC2.

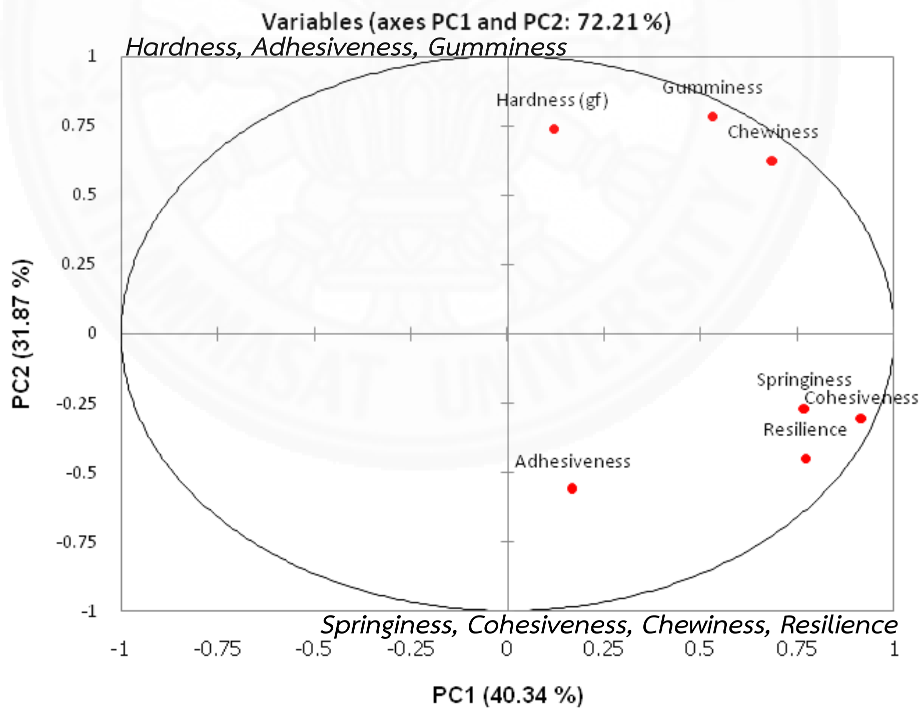

Figure 4.8 Loading plot graph of texture properties such as hardness, adhesiveness, springiness, cohesiveness, gumminess, chewiness and resilience of experiment butter cakes and commercially butter cakes

The result of clustering the texture properties of experimental butter cakes and commercial butter cakes by using Hierarchical Cluster analysis method was as shown in Figure 4.9. By considering the Euclidean distance between the variables, the closet distance between measured variables would be placed in the same group. The bi-plot of texture properties and butter cakes from 27 experimental butter cakes and 12 commercial butter cakes using PCA technique and Hierarchical Cluster analysis was created as shown in Figure 4.10. The figure indicated that the 27 experimental butter cakes and 12 commercial butter cakes could be divided into 4 groups as following.

Group I : Cake with low springiness, cohesiveness, gumminess and chewiness (C6, C12, E2, E3, E4, E8, E15, E16, E18, E20, E23, E25, E26 and E27)

Group II : Cake with low springiness, cohesiveness and resilience but high in gumminess (C3, C4, E5, E6, E7 and E22)

Group III : Cake with high in springiness, cohesiveness, gumminess and chewiness but low in resilience (C1, C2, C8, C10, C11 and E13)

Group IV : Cake with high springiness, cohesiveness and resilience (C5, C7, C9, E1, E9, E10, E11, E12, E14, E17, E19, E21 and E24)

Note: C1-C12 were commercial butter cakes and E1-E27 were experimental butter cakes. The group of butter cakes could be described by the relationship diagram as shown in Figure 4.11.

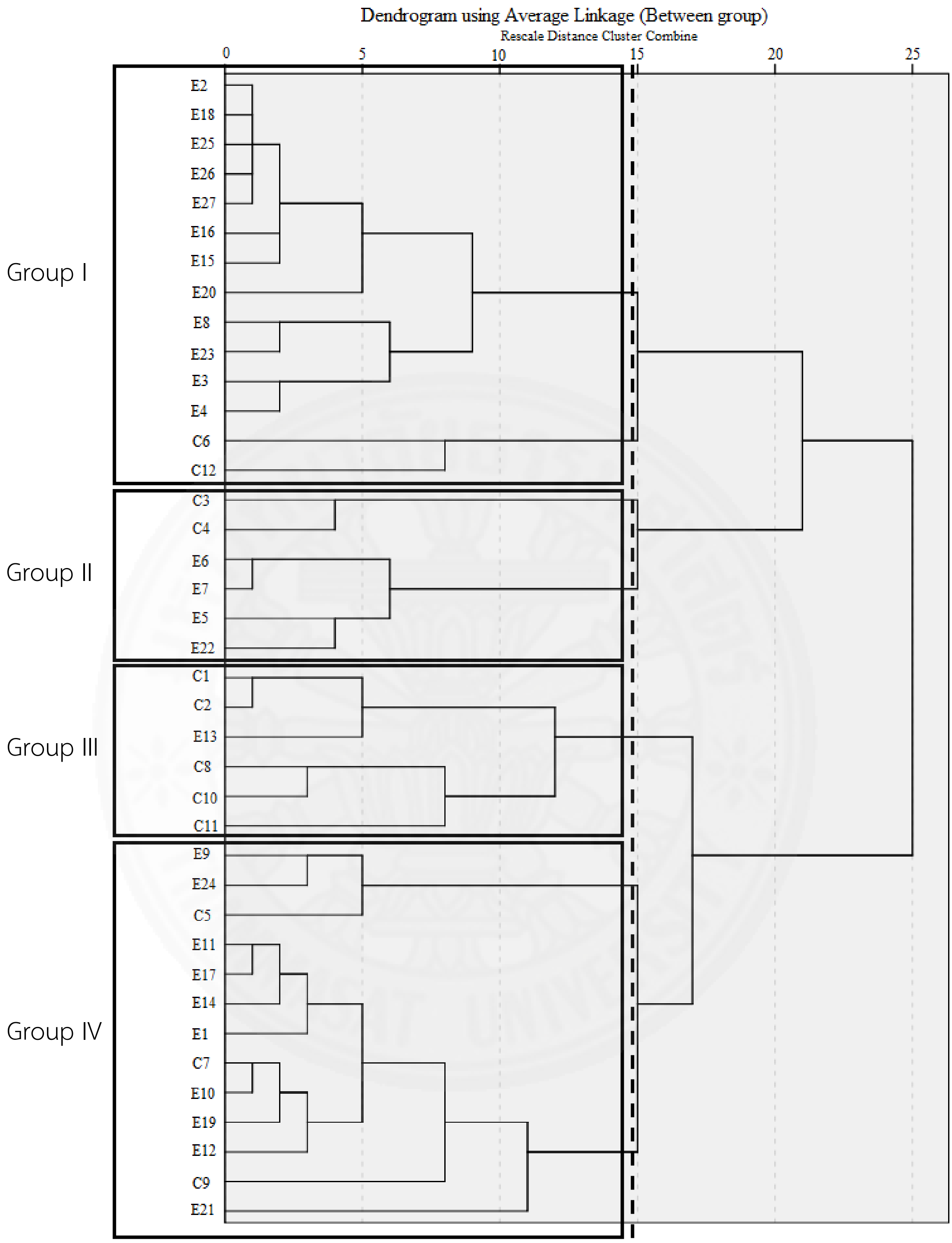

Figure 4.9 Dendrogram of hierarchical cluster analysis of the texture properties of 27 experimental butter cakes (E1-E27) and 12 commercial butter cakes (C1-C12)

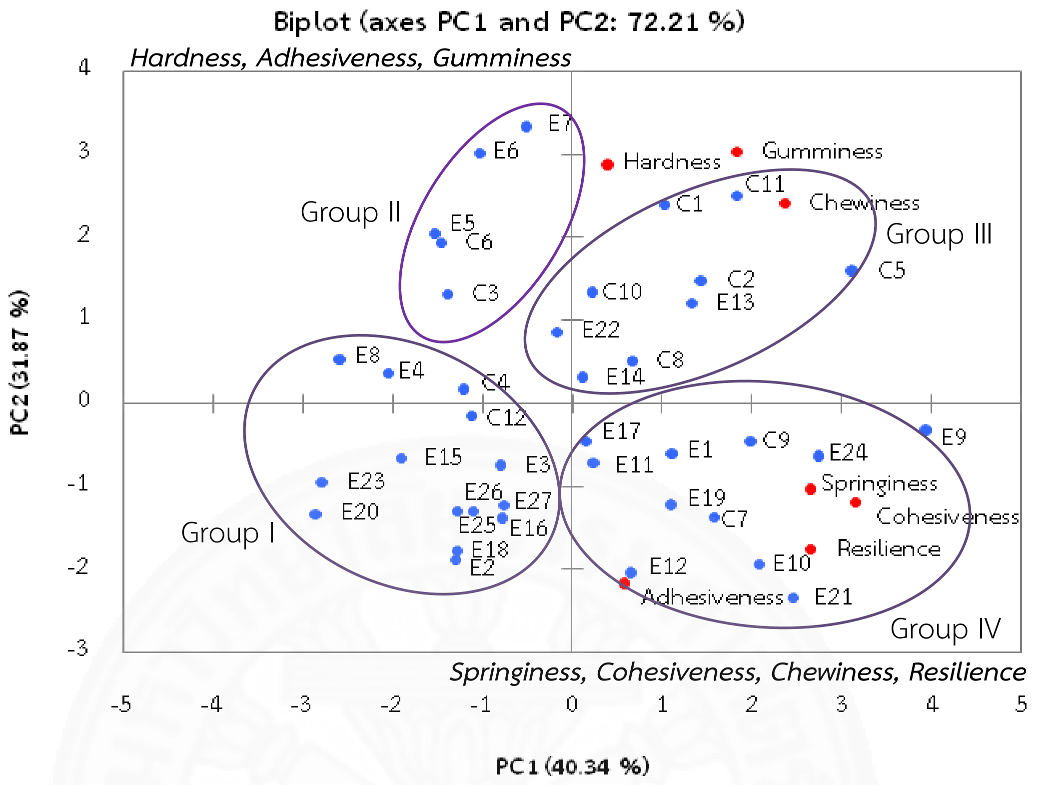

Figure 4.10 Bi-plot of texture properties of experimental butter cakes (E1-E27) and commercial butter cakes (C1-C12) by using PCA technique with the circle presenting different groups of cakes

From the result of clustering the texture properties of experimental butter cakes and commercial butter cakes into 4 groups. The representative cake ingredient from each group was selected from the middle euclidean distance for each group from the cluster analysis as shown in Table 4.12.

The 4 groups of representative butter cakes made from various ratio of ingredient combinations could be described their group characteristic based on texture properties as shown in Table 4.13.

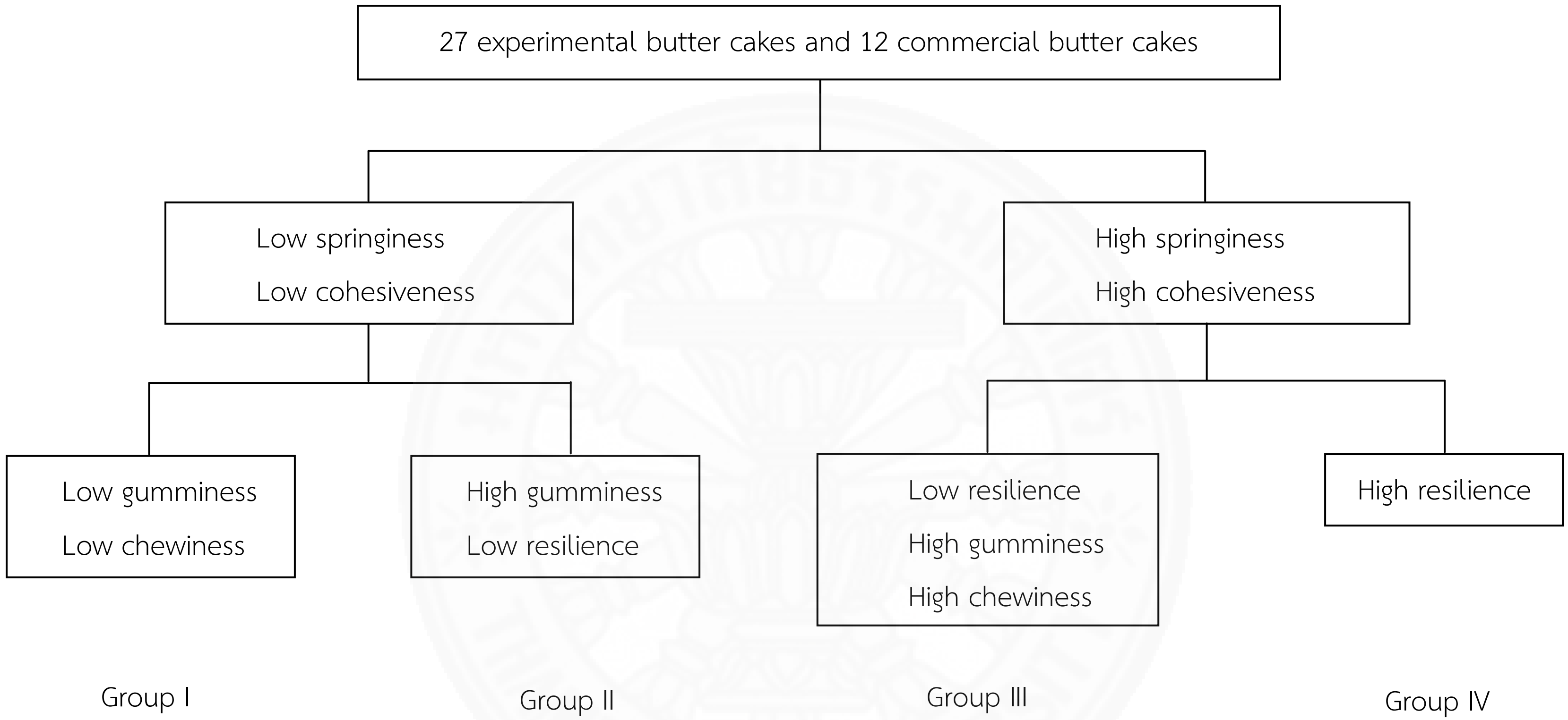

Figure 4.11 Group of commercial and experimental butter cake classified by texture properties using PCA and cluster analysis methods

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Table 4.12 The four representative cake ingredient from each group of experimental butter cakes

Cake	Ingredient level (Code)				Ingredient level (percent of weight flour)			
group	Sugar	Butter	Margarine	Eggs	Sugar	Butter	Margarine	Eggs
I	-1	1	1	1	110	105	75	105
II	-1	1	1	-1	110	105	75	55
III	-1	-1	1	1	110	55	75	105
IV	-1	-1	-1	-1	110	55	25	55

Table 4.13 The characteristic based on texture properties of four representative cakes made from various ratio of ingredient combinations

Butter cake	Ingredients	Texture properties
$S_LB_HM_HE_H$	Low ratio of sugar, high ratio of butter, margarine and egg	Low springiness, cohesiveness, gumminess and chewiness
$S_LB_HM_HE_L$	Low ratio of sugar and egg, high ratio of butter and margarine	Low springiness, cohesiveness and resilience but high in gumminess
$S_LB_LM_HE_H$	Low ratio of sugar and butter, high ratio of margarine and egg	High springiness, cohesiveness, gumminess and chewiness but low in resilience
$S_LB_LM_LE_L$	Low ratio of sugar, butter, margarine and egg	High springiness, cohesiveness and resilience

4.2.4 Microstructure and image analysis of butter cake

The representative butter cakes from each group was brought to investigate the cake microstructure using a stereo microscope with a magnification of 8 and 32 times as shown in Figure 4.12 and 4.13, respectively. It could be seen that $S_LB_HM_HE_L$ and $S_LB_LM_LE_L$ had bigger pore cell than the cake $S_LB_HM_HE_H$ and $S_LL_BH_MH_E$.

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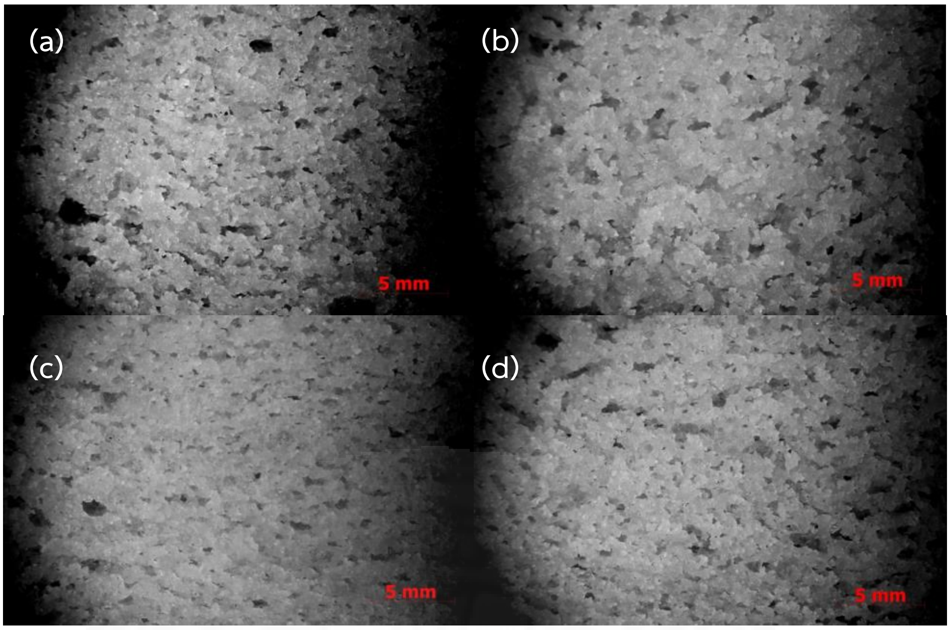

Figure 4.12 Crumb cake image of butter cake at 8x magnification. (a) $S_LB_HM_HE_H$, (b) $S_LB_HM_HE_L$, (c) $S_LB_LM_HE_H$ and (d) $S_LB_LM_LE_L$

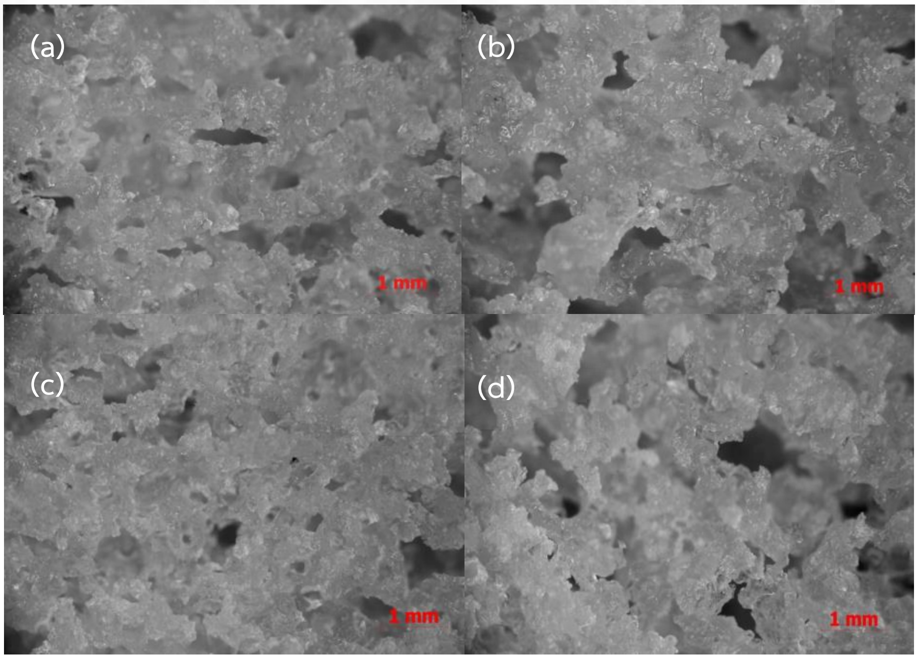

Figure 4.13 Crumb cake image of butter cake at 32x magnification. (a) $S_LB_HM_HE_H$, (b) $S_LB_HM_HE_L$, (c) $S_LB_LM_HE_H$ and (d) $S_LB_LM_LE_L$

The crumb images of butter cake at 8x magnification from each group were analyzed by ImageJ program. This program adjusted the contrast between two phases (pore and solid) in the image and convert color of image to gray scale as shown in Figure 4.14. It could be seen that $S_LB_HM_HE_L$ revealed a number of large area pore cells greater than the others, so the image analysis result showed that cake from this group had high value of mean cell area but a number of cells per area was less. $S_LB_HM_HE_L$ was made from high ratio of fat (butter and margarine) and low ratio of eggs in the formulation, so the batter was dense and heavy because of insufficient ingredient function to incorporate air and emulsify immiscible liquid in batter, so that the batter might be inferior in incorporating air cells during mixing. Hence the pore distribution in cake structure was not regular (small and large sizes of pore cells), the mean cell area was high but number of air cells per unit area was low. It was agree with the previous study, butter cake with 100% of butter had lower numbers of air cell and larger average air cell size than butter cake with 10% of fat replacement (Marina et al., 2016). In contrast, $S_LB_LM_HE_H$ showed a number of small area pore cell, greater than the others so the image analysis result showed that cake from this group had low value of mean cell area but a number of cells was high.

Table 4.14 showed mean cell area and number of air cells per unit area of butter cakes 4 groups. By conducting the statistical analysis, it was found that mean cell area and number of air cells per unit area of butter cakes 4 groups were not significantly different ($p>0.05$). Anyway, the mean cell area of $S_LB_HM_HE_L$ was largest with the lowest in a number of air cell per unit area. In contrast, the mean cell area of $S_LB_LM_HE_H$ was lowest with the highest number of air cell per unit area. $S_LB_LM_HE_H$ were made from high ratio of eggs that contribute to cake structure, incorporate air when beaten, provide liquid, fat, and protein, and emulsify fat with liquid ingredients, the image analysis results showed high value of a number of air cells per unit area. In addition, it was found that increasing the amount of eggs and starch in the mixture resulted in increased in batter viscosity. Due to the increase in egg and starch content, which increase protein in the mixture. This prevents loss of air cells and makes the batter more stable (Hesso et al., 2015b). This finding was agreed with the microstructure of sponge cake, the number of air cell per unit area was higher from

37.83 to 52.20 cell/cm^2 in the cake which had whey protein isolate 12.5% and 100%, respectively (Díaz-Ramírez et al., 2016).

Table 4.15 showed pore area distribution, it could be seen that all of butter cake had the small pore cell area distribution at 0-0.005 mm^2 in high percentage. The pore area distribution at 0-0.005 mm^2 of $S_LB_HM_HE_H$, $S_LB_HM_HE_L$, $S_LB_LM_HE_H$ and $S_LB_LM_LE_L$ were 73.19, 71.90, 69.75 and 70.91 %, respectively.

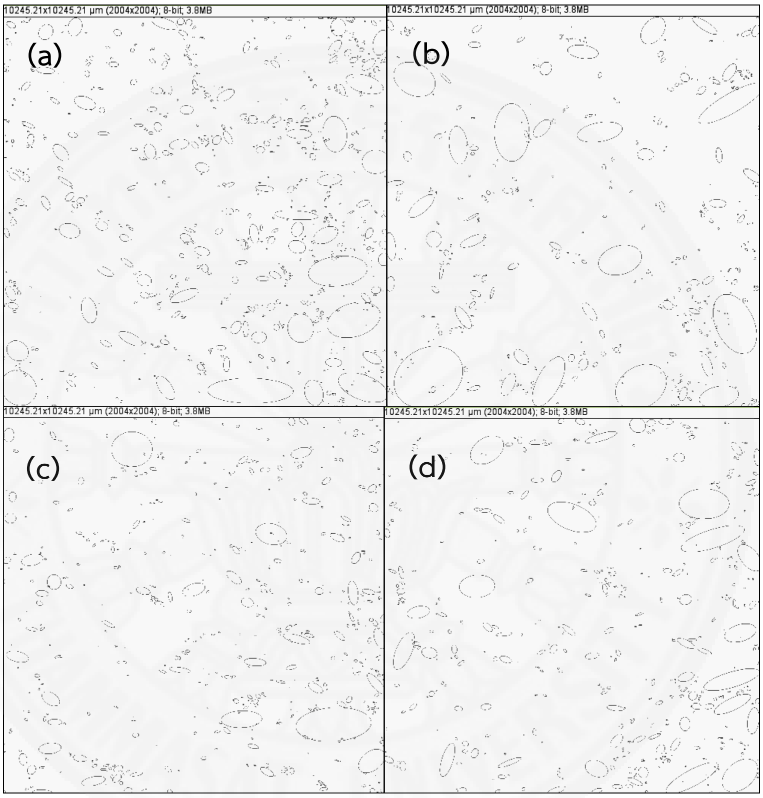

Figure 4.14 Image analysis of crumb cake image of butter cake at 8x magnification. (a) ellipse of air cell from image analysis of $S_LB_HM_HE_H$, (b) ellipse of air cell from image analysis of $S_LB_HM_HE_L$, (c) ellipse of air cell from image analysis of $S_LB_LM_HE_H$, (d) ellipse of air cell from image analysis of $S_LB_LM_LE_L$

Ref. code: 25615409300216VXU

Table 4.14 Mean cell area and number of air cell per unit area of representative butter cakes from each group

Butter cake	Mean cell area (mm^2) ^{ns}	Number of air cell per unit area (cell/mm^2) ^{ns}
$S_LB_HM_HE_H$	0.0216 ± 0.002	46.4 ± 4.9
$S_LB_HM_HE_L$	0.0326 ± 0.005	30.3 ± 2.8
$S_LB_LM_HE_H$	0.0189 ± 0.003	53.6 ± 10.3
$S_LB_LM_LE_L$	0.0231 ± 0.014	43.2 ± 0.3

Note: ^{ns} not significantly different (p>0.05) and mean values±SD.

Table 4.15 Percentages of pores area distribution of representative butter cakes from each group

Range of pore area distribution (mm^2)	$S_LB_HM_HE_H$ (%)	$S_LB_HM_HE_L$ (%)	$S_LB_LM_HE_H$ (%)	$S_LB_LM_LE_L$ (%)
0-0.005	73.19 ± 2.2	71.90 ± 0.8	69.75 ± 3.7	70.91 ± 2.8
0.005-0.010	8.08 ± 0.1	7.78 ± 1.0	10.40 ± 0.1	8.08 ± 0.1
0.010-0.050	11.98 ± 1.9	12.14 ± 1.4	3.33 ± 2.4	13.78 ± 2.8
0.050-0.100	2.72 ± 0.3	2.37 ± 0.6	2.65 ± 0.1	2.76 ± 1.0
0.100-1.000	3.76 ± 0.1	5.01 ± 0.1	3.69 ± 1.3	4.28 ± 0.7
1.000-2.000	0.28 ± 0.1	0.53 ± 0.3	0.09 ± 0.1	0.19 ± 0.2
2.000-3.000	0.07 ± 0.1	0.26 ± 0.1	0.09 ± 0.1	0.00 ± 0.1

Note: mean values±SD.

When the pore area distribution between at 0 and 0.005 mm^2 were investigated. It can be seen that all of butter cakes had small pore area distribution between 0 and 0.0005 mm^2 as shown in Figure 4.15. $S_LB_HM_HE_L$ had the highest percentage of area between 0 and 0.0005 mm^2, the second from the highest was $S_LB_HM_HE_H$ but the number of large pore area of $S_LB_HM_HE_L$ tended to be less than

$S_LB_HM_HE_H$. $S_LB_LM_HE_H$ had the similar size of pore area but the large pore area of $S_LB_LM_LE_L$ tended to be higher than $S_LB_LM_HE_H$.

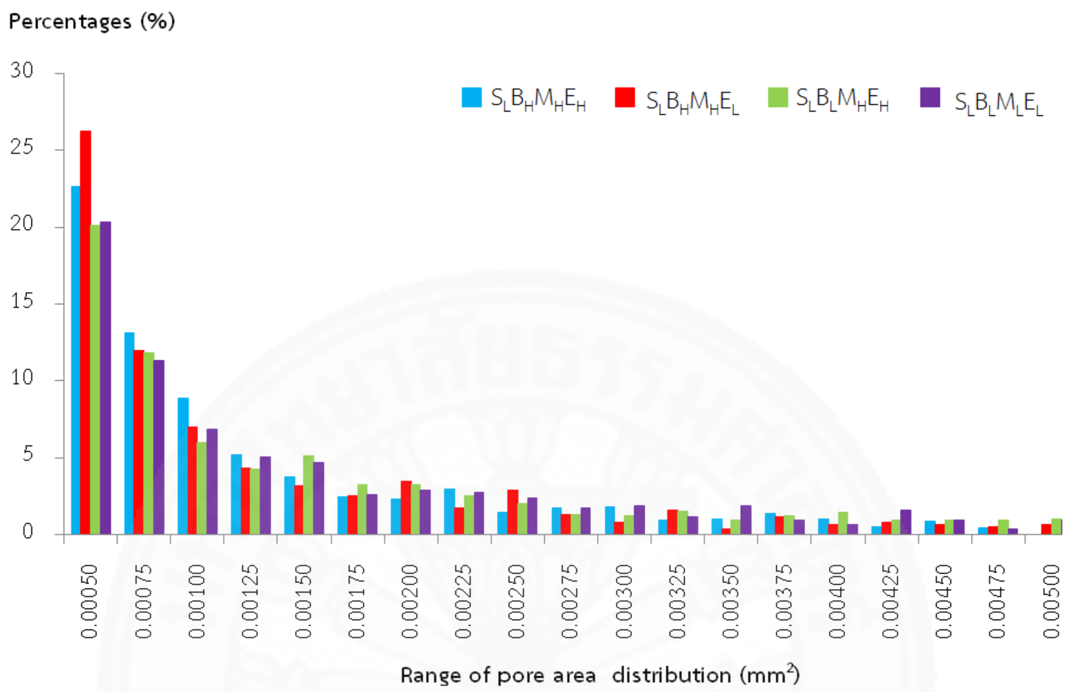

Figure 4.15 Pore area distribution of representative butter cakes from each group at 0-0.005 mm^2

4.2.5 Quantitative descriptive analysis (QDA) of the group representative of butter cakes

From clustering experimental butter cakes together with commercial butter cakes based on their texture properties using Hierarchical cluster analysis method, the analysis results suggested that it could be divided butter cakes into 4 groups. After that the representative from each group was selected to evaluate sensory qualities by QDA method. There were panel of 10 assessors, 7 females and 3 males whose age between 24 and 55 years old, which age was followed by Heenan et al. (2009), to describe the 4 groups of butter cake. Assessors developed a descriptive vocabulary and contributed its definition in 8 training times with 2 hours each session and used a 15 cm line scale. The vocabularies from evaluating butter cakes 4 groups included appearance (color intensity and pore size), texture (hardness and cohesiveness), flavor (butter flavor), taste (sweet and salt) and after taste (butter). The descriptive vocabulary, definitions and reference of each attribute for sensory assessors in descriptive analysis was shown in Table 4.16.

Table 4.16 Descriptive vocabulary, definitions and reference intensity used by trained assessors in evaluating representative butter cakes from each group

Attribute	Definition	Reference intensity (cm.)
Appearance:		
Color intensity	Color intensity ranges from white to dark brown	Low (2.0) : white bread, Farmhouse® High (11.0) : stick biscuit, Lotus®
Pore size	The size of the air cell in the texture of the cake	Low (1.0) : puff makeup, Camella® High (13.0) : puff cleanser, Camella®
Texture:		
Hardness	The force used to chew the sample with a molar tooth	Low (2.0) : jelly dessert with fruit flavor, Pipo® High (11.0) : wafer, Laisanne®
Cohesiveness	Sample volumes are broken apart. By pressing with a finger, the structure of the cake breaks apart	Low (1.0) : Khanom Ping, Kanom BanArjarn® High (14.0) : butter cake, S&P®
Flavor:		
Butter	Intensity of butter flavor when chewing sample	Low (2.0): butter essence, Winner®, diluted in water (0.5 ml:100 ml) High (12.0) : butter essence, Winner®, diluted in water (5 ml:100 ml)

Source: Adapted from Heenan et al. (2009); Heenan et al. (2010)

Table 4.16 Descriptive vocabulary, definitions and reference intensity used by trained assessors in evaluating representative butter cakes from each group (cont.)

Attribute	Definition	Reference intensity
Taste:		
Sweet	Intensity of sweetness when chewing sample	Low (3.0) : sugar, Mitr Phol®, diluted in water (10 g:100 ml) High (13.0) : sugar, Mitr Phol®, diluted in water (30 g:100 ml)
Salt	Intensity of saltness when chewing sample	Low (0.5) : salt, Prung Thip®, diluted in water (0.1 g:100 ml) High (11.0) : salt, Prung Thip®, diluted in water (1 g:100 ml)
After taste:		
Butter	Intensity of butter flavor in mouth after swallowing	Low (1.0) : white bread, Farmhouse® High (14.0) : sugar-butter bread, Farmhouse®

Source: Adapted from Heenan et al. (2009); Heenan et al. (2010)

The result of QDA was shown in Table 4.17. All of attributes (color intensity, pore size, hardness, cohesiveness, butter flavor, sweet, salt and after taste butter) had significantly difference ($p \leq 0.05$). $S_LB_HM_HE_H$, $S_LB_HM_HE_L$, $S_LB_LM_HE_H$ showed higher color intensity than $S_LB_LM_LE_L$ because $S_LB_HM_HE_H$ and $S_LB_HM_HE_L$ made from butter that had yellow pigment of carotene. $S_LB_LM_HE_H$ made from margarine that added yellow color to imitate yellow color of butter. Hardness of $S_LB_HM_HE_L$ had the highest value because this cake formula used low ratio of eggs, so the cake structure was really tight. The result agreed with Heenan et al. (2010), the cake with high ratio of butter and margarine had high scores of hardness, which evaluated by QDA method. Cohesiveness of $S_LB_HM_HE_H$ and $S_LB_HM_HE_L$ showed the lowest value but $S_LB_LM_HE_H$ and $S_LB_LM_LE_L$ showed the highest one. $S_LB_HM_HE_H$ and $S_LB_HM_HE_L$ had higher value in butter flavor, sweet, salt and after taste than $S_LB_LM_HE_H$ and $S_LB_LM_LE_L$. $S_LB_HM_HE_H$, $S_LB_LM_HE_H$ and $S_LB_LM_LE_L$ had higher value in pore size than $S_LB_HM_HE_L$, this result could explain in accordance with pore size area distribution in that $S_LB_HM_HE_L$ had high percentage of pore size area distribution.

Table 4.17 Descriptive analysis mean score of representative butter cakes from each group

Attribute	$S_LB_HM_HE_H$ (%)	$S_LB_HM_HE_L$ (%)	$S_LB_LM_HE_H$ (%)	$S_LB_LM_LE_L$ (%)
Color intensity	7.10 ± 0.88^a	6.95 ± 0.76^a	6.65 ± 0.67^a	5.30 ± 0.67^b
Pore size	7.10 ± 0.74^a	5.20 ± 0.79^c	6.40 ± 0.84^b	6.70 ± 0.82^{ab}
Hardness	4.60 ± 0.70^d	6.80 ± 0.42^a	5.80 ± 0.42^b	5.10 ± 0.74^c
Cohesiveness	7.20 ± 0.79^b	7.00 ± 0.82^b	9.00 ± 0.94^a	9.5 ± 0.85^a
Butter flavor	8.78 ± 0.63^a	9.00 ± 0.82^a	7.27 ± 0.24^b	6.44 ± 0.37^c
Sweet	8.32 ± 0.16^a	7.85 ± 0.75^{ab}	6.82 ± 0.94^b	6.75 ± 0.91^b
Salt	5.57 ± 0.23^a	5.58 ± 0.66^a	4.13 ± 0.37^b	3.85 ± 0.81^b
After taste butter	10.03 ± 0.25^a	9.78 ± 0.75^a	7.41 ± 0.95^b	6.79 ± 0.75^b

Note: Mean values with different letters in each row are significantly different ($p \le 0.05$) as determined by Duncan's new multiple range test (DMRT), and mean values±SD.

4.2.6 Studying the relationship between the main ingredients and the properties of butter cakes

Based on the analysis of microstructure (mean cell area and number of air cell per unit area), texture properties (hardness, springiness, cohesiveness, gumminess, chewiness and resilience) and sensory properties (color intensity, pore size, hardness, cohesiveness, butter flavor, sweet, salt and after taste butter), the average value of each attribute was used to analyze the correlation among each other by PCA technique as shown in Table 4.18. It could be explained that the total variance was 90.17% using principal component 1 and 2 (PC1 and PC2). As shown in Figure 4.16, PC1 (horizontal axis), which described the variance of 57.03%, had a positive relationship with QDA hardness, hardness and mean cell area, and had a negative relationship with QDA pore size, QDA cohesiveness, springiness, resilience and number of air cells per unit area. PC2 (vertical axis), which describes the variance of 33.14%, had a positive relationship with cohesiveness, gumminess and chewiness, and had a negative relationship with QDA color intensity.

Table 4.18 Factor loading of microstructure, texture properties and sensory properties of representative butter cakes from each group

Texture properties	Factor loading	
	PC1	PC2
QDA color intensity	0.524	**-0.538**
QDA pore size	**-0.896**	-0.444
QDA hardness	**0.821**	0.548
QDA cohesiveness	**-0.734**	0.666
Hardness	**0.890**	0.454
Springiness	**-0.732**	0.605
Cohesiveness	-0.633	**0.773**
Gumminess	0.664	**0.734**
Chewiness	0.384	**0.892**
Resilience	**-0.831**	0.489
Mean cell area	**0.914**	0.049
Number of air cell per unit area	**-0.843**	0.020

Note: Bold letter refers to the factor loadings which explained the PC1 and PC2.

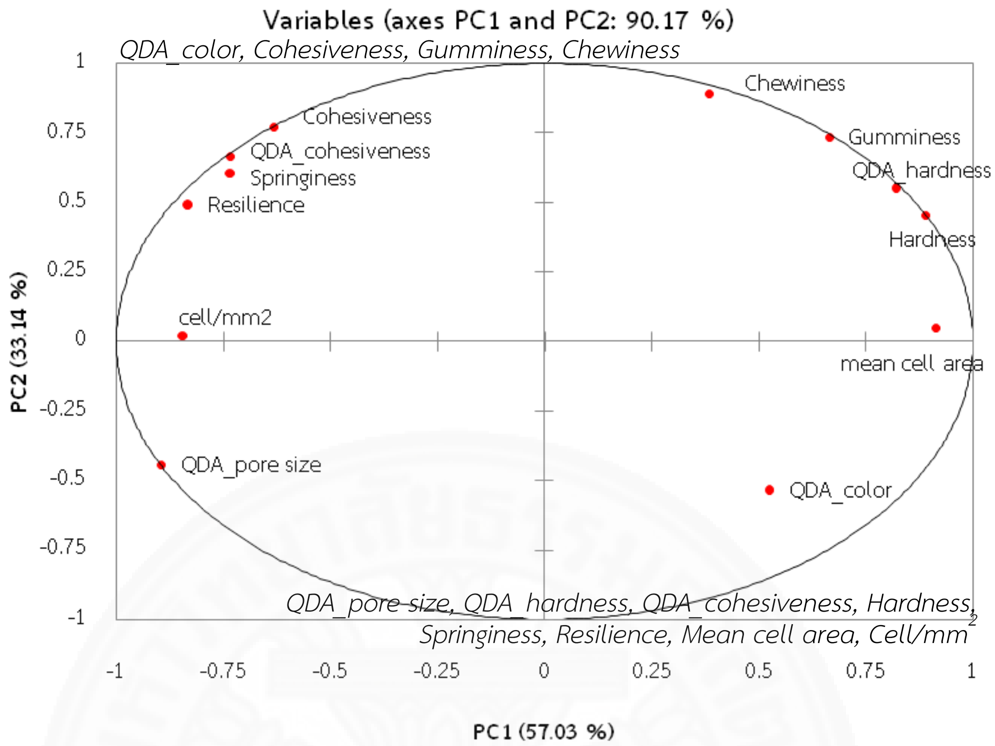

Figure 4.16 Loading plot graph of microstructure, texture properties and sensory properties of representative butter cakes from each group

The correlation of image analysis result, texture properties and sensory properties of butter cakes 4 groups was analyzed by PCA technique, the bi-plot was created as shown in Figure 4.17. $S_LB_HM_HE_H$ used high level of margarine which entrapped the air during mixing and expanded during baking, and also used high level of eggs which are able to incorporate more air cells during mixing. So hardness, springiness, cohesiveness, gumminess, chewiness and resilience of cake were low values, so did the QDA hardness and cohesiveness. Moreover, butter and margarine had yellow pigment, so QDA color intensity showed high value too. In addition, this cake group used high level of eggs which enable to incorporate air and emulsify fat and liquid to provide cake structure and volume. Therefore the image analysis result of $S_LB_HM_HE_H$ showed higher number of air cells per unit area. Since $S_LB_HM_HE_L$ used low level of eggs, so the batter was dense and heavy because of insufficient ingredient function to incorporate air and emulsify immiscible liquid in batter. The cake structure of $S_LB_HM_HE_L$ was dense so that the value of hardness, gumminess and chewiness was high, so did the QDA hardness. Since this cake group used low level of eggs, so that batter might be inferior in incorporating air cells during mixing, the pore distribution in cake structure was not regular (small and large sizes of pore cells). Therefore the mean cell area from this cake group was high but number of air cells per unit area was low, which was in accordance with the result of QDA pore size.

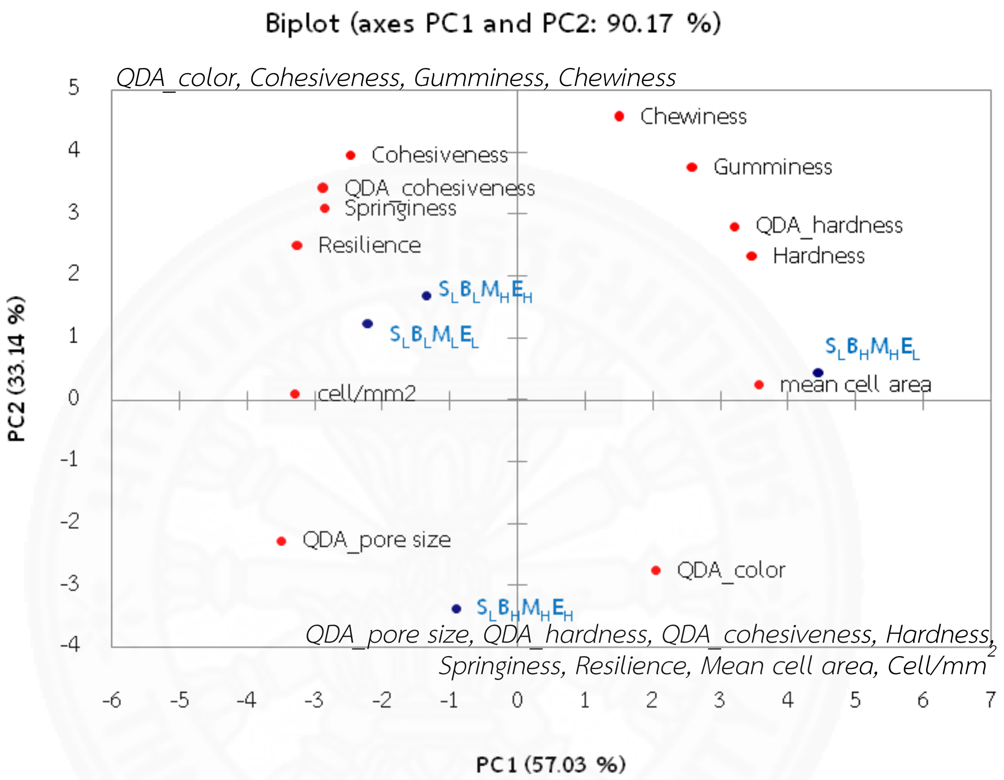

Figure 4.17 Bi-plot of microstructure, texture properties and sensory properties of representative butter cakes from each group

$S_LB_LM_HE_H$ used high level of margarine and egg which formed a good cake structure and texture, because margarine had a function in entrapping air cells and eggs had a function of incorporating air and emulsification, formed cake structure. So pore size of cake was smooth, mean cell area was low but high in number of air cells per unit area, hardness, springiness, cohesiveness, gumminess, chewiness and resilience, so did the QDA hardness and cohesiveness. $S_LB_LM_LE_L$ was similar to $S_LB_LM_HE_H$, but it had high value of resilience. Because $S_LB_LM_LE_L$ used high ratio of margarine which is unsaturated fat that coated air cells so that it help retard of the cake structure after compression and decrease in elastic properties of cake structure so resilience value of $S_LB_LM_HE_H$ was less than $S_LB_LM_LE_L$

4.3 Studying the effect of storage temperature and time on the properties of butter cakes

The effect of storage temperature and time on the representative cake from each group was studied. The cake samples at $4\pm2^{\circ}C$ were collected at 0-6 days and cake samples at $25\pm2^{\circ}C$ were collected at 0-18 days. Table 4.19 and 4.20 showed the water activity and thiobarbituric acid (TBA) values of representative butter cakes from each group at $25^{\circ}C$ during 6 days and $4^{\circ}C$ during 18 days of storage period, respectively. It was found water activity and thiobarbituric acid (TBA) values were significantly difference ($p\leq0.05$).

From Table 4.19, the water activity values of all cakes stored at $25^{\circ}C$ were between 0.80-0.90. $S_LB_HM_HE_H$ stored at $25^{\circ}C$ for 0 and 2 days, and $S_LB_LM_HE_H$ stored at $25^{\circ}C$ for 0 day had the highest values of water activity. But $S_LB_HM_HE_L$ stored at $25^{\circ}C$ for 4 and 6 days, and $S_LB_LM_LE_L$ stored at $25^{\circ}C$ for 6 day had the lowest values of water activity. From Table 4.20, the water activity values of all cakes stored at $4^{\circ}C$ were between 0.82-0.91. $S_LB_HM_HE_H$ stored at $4^{\circ}C$ for 0 day, and $S_LB_LM_HE_H$ stored at $4^{\circ}C$ for 0 day had the highest values of water activity. But $S_LB_LM_LE_L$ stored at $4^{\circ}C$ for 18 day had the lowest values of water activity. The cakes with high ratio of margarine and eggs had high values of water activity, because margarine is mainly composed of fat that could inhibit amylose and amylopectin from forming bridges between swollen starch granules ultimately prevents retrogradation (Schiraldi and Fessas, 2001) and egg white consists of water up to 88% (Wilderjans et al., 2013) which causing the amount of water to remain in the cake. As the storage times increased, the water activity value of each cake group decreased because of retrogradation reaction, some water migrated from amorphous to crystalline starch (Schiraldi and Fessas, 2001).

From Table 4.19, the TBA values of representative butter cakes from each group stored at $25^{\circ}C$ were between 0.72-2.88 mg of malonaldehyde/kg. $S_LB_HM_HE_L$ stored at $25^{\circ}C$ for 6 day had the highest values of TBA. But $S_LB_HM_HE_H$ stored at $25^{\circ}C$ for

0 day, $S_LB_HM_HE_L$ stored at 25°C for 0 and 2 days, and $S_LB_LM_LE_L$ stored at 25°C for 0 day had the lowest values of TBA.

From Table 4.20, the TBA values of representative butter cakes from each group stored at 4°C were between 0.72-1.88 mg of malonaldehyde/kg. $S_LB_LM_HE_H$ stored at 4°C for 18 day and $S_LB_LM_LE_L$ stored at 4°C for 18 day had the highest values of TBA. But $S_LB_HM_HE_H$ stored at 4°C for 0 and 6 days, $S_LB_HM_HE_L$ stored at 4°C for 0 and 6 days and $S_LB_LM_LE_L$ stored at 4°C for 0 day had the lowest values of TBA. All representative cake from each group were stored for 0 and 2 days had the low values of TBA but when stored longer, the TBA value would increase, especially for the cakes that contain high ratio of butter and margarine. This result was in good agreement with Hafez (2012) who studied the cakes stored at room temperatures for 21 days of storage period and found that TBA values of butter cake increased from 0.527 to 0.969 mg of malonaldehyde/kg. Moreover, TBA values of the cake which stored at 25°C was higher than the cake which stored at 4°C because butter cake used butter or margarine as fat ingredient which tended to become rancid after prolonged storage because of the oxidation of polyunsaturated fatty acids (Smith et al., 2004). Lipid oxidation lowered the quality and nutritional value of food (Suja et al., 2005). Varlik et al. (1993) reported that TBA value should be less than 3 mg of malonaldehyde/kg in a very good material and should not exceed 5 mg of malonaldehyde/kg in a good material. Since all cake groups either stored at 4°C for 18 days or 25°C for 6 days had the TBA value less than 3 mg of malonaldehyde/kg until the last day of storage, it can be concluded that the cakes stored at both temperatures would still be accepted for no rancid taste and odor.

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Table 4.19 a_w and TBA values of representative butter cakes from each group stored at 25°C for 6 days

Butter cake	Time (days)	a_w	TBA values (mg of malonaldehyde/kg)
$S_LB_HM_HE_H$	0	0.89 ± 0.01^{a}	0.78 ± 0.02^{g}
	2	0.89 ± 0.01^{a}	1.07 ± 0.13^{cde}
	4	0.86 ± 0.01^{b}	1.12 ± 0.02^{cd}
	6	0.87 ± 0.01^{b}	1.39 ± 0.01^{b}
$S_LB_HM_HE_L$	0	0.86 ± 0.01^{b}	0.72 ± 0.01^{g}
	2	0.86 ± 0.02^{b}	0.77 ± 0.03^{g}
	4	0.81 ± 0.02^{ef}	0.92 ± 0.02^{f}
	6	0.80 ± 0.02^{f}	2.88 ± 0.04^{a}
$S_LB_LM_HE_H$	0	0.90 ± 0.01^{a}	1.05 ± 0.03^{de}
	2	0.87 ± 0.01^{b}	1.06 ± 0.02^{de}
	4	0.86 ± 0.01^{b}	1.09 ± 0.01^{cde}
	6	0.86 ± 0.01^{b}	1.36 ± 0.02^{b}
$S_LB_LM_LE_L$	0	0.84 ± 0.01^{c}	0.78 ± 0.01^{g}
	2	0.83 ± 0.01^{cd}	1.01 ± 0.02^{e}
	4	0.82 ± 0.01^{de}	1.02 ± 0.04^{e}
	6	0.80 ± 0.01^{ef}	1.16 ± 0.03^{c}

Note: Mean values with different letters in each column were significantly different ($p \leq 0.05$) as determined by Duncan's new multiple range test (DMRT), and mean values±SD.

Table 4.20 a_w and TBA values of representative butter cakes from each group stored at 4°C for 18 days

Butter cake	Time (days)	a_w	TBA values (mg of malonaldehyde/kg)
$S_LB_HM_HE_H$	0	0.91 ± 0.02^{a}	0.75 ± 0.01^{g}
	6	0.87 ± 0.02^{cd}	0.82 ± 0.01^{fg}
	12	0.88 ± 0.02^{bc}	0.95 ± 0.02^{de}
	18	0.86 ± 0.02^{d}	1.03 ± 0.07^{cd}
$S_LB_HM_HE_L$	0	0.87 ± 0.03^{cd}	0.72 ± 0.02^{g}
	6	0.84 ± 0.03^{ef}	0.73 ± 0.01^{g}
	12	0.84 ± 0.01^{ef}	0.88 ± 0.02^{ef}
	18	0.85 ± 0.01^{e}	1.11 ± 0.01^{c}
$S_LB_LM_HE_H$	0	0.91 ± 0.01^{a}	1.13 ± 0.10^{c}
	6	0.87 ± 0.01^{cd}	1.44 ± 0.04^{b}
	12	0.88 ± 0.01^{bc}	1.52 ± 0.01^{b}
	18	0.87 ± 0.01^{cd}	1.88 ± 0.11^{a}
$S_LB_LM_LE_L$	0	0.83 ± 0.01^{fg}	0.77 ± 0.03^{fg}
	6	0.83 ± 0.01^{fg}	0.97 ± 0.01^{de}
	12	0.83 ± 0.01^{fg}	1.52 ± 0.01^{b}
	18	0.82 ± 0.01^{h}	1.88 ± 0.11^{a}

Note: Mean values with different letters in each column were significantly different ($p \leq 0.05$) as determined by Duncan's new multiple range test (DMRT), and mean values±SD.

Table 4.21 and 4.22 showed the texture properties values of representative butter cakes from each group at 25°C during 6 days and 4°C during 18 days of storage period, respectively. It was found that the values of hardness, springiness, cohesiveness, gumminess, chewiness and resilience were significantly difference ($p \leq 0.05$).

From Table 4.21, hardness values of all cakes stored at 25°C were between 294.49-715.81 g_f. $S_LB_HM_HE_L$ stored at 25°C for 4 and 6 days had the highest values of hardness. But $S_LB_HM_HE_H$ stored at 25°C for 0 and 2 days had the lowest values of hardness. Springiness values of all cakes stored at 25°C were between 0.62-0.88. $S_LB_LM_HE_H$ stored at 25°C for 0 day had the highest values of springiness. But $S_LB_HM_HE_L$ stored at 25°C for 6 days had the lowest values of springiness. Cohesiveness values of all cakes stored at 25°C were between 0.27-0.56. $S_LB_LM_HE_H$ stored at 25°C for 0 day and $S_LB_LM_LE_L$ stored at 25°C for 0 and 2 days had the highest values of cohesiveness. But $S_LB_HM_HE_H$ stored at 25°C for 4 and 6 days had the lowest values of cohesiveness. Gumminess values of all cakes stored at 25°C were between 139.39-345.84 g_f. $S_LB_HM_HE_L$ stored at 25°C for 6 day had the highest values of gumminess. But $S_LB_HM_HE_H$ stored at 25°C for 0, 2, 4 and 6 days had the lowest values of gumminess. Chewiness values of all cakes stored at 25°C were between 113.43-273.93 g_f. $S_LB_HM_HE_L$ stored at 25°C for 4 and 6 day had the highest values of chewiness. But $S_LB_HM_HE_H$ stored at 25°C for 0, 2, 4 and 6 days had the lowest values of chewiness. Resilience values of all cakes stored at 25°C were between 0.13-0.25. $S_LB_LM_LE_L$ stored at 25°C for 0 and 2 days had the highest values of resilience. But $S_LB_HM_HE_H$ stored at 25°C for 4 and 6 days had the lowest values of resilience.

From Table 4.22, hardness values of all cakes stored at 4°C were between 308.87-964.46 g_f. $S_LB_HM_HE_L$ stored at 4°C for 18 days had the highest values of hardness. But $S_LB_HM_HE_H$ stored at 4°C for 0 day had the lowest values of hardness. Springiness values of all cakes stored at 4°C were between 0.56-0.86. $S_LB_LM_HE_H$ and $S_LB_LM_LE_L$ stored at 4°C for 0 day had the highest values of springiness. But $S_LB_HM_HE_H$ and $S_LB_HM_HE_L$ stored at 4°C for 12 and 18 days had the lowest values of springiness. Cohesiveness values of all cakes stored at 4°C were between 0.21-0.57. $S_LB_LM_HE_H$ and $S_LB_LM_LE_L$ stored at 4°C for 0 day had the highest values of cohesiveness. But $S_LB_HM_HE_H$ stored at 4°C for 18 days had the lowest values of cohesiveness. Gumminess values of all cakes stored at 4°C were between 143.80-387.99 g_f. $S_LB_HM_HE_L$ stored at 4°C for 18 day had the highest values of gumminess. But $S_LB_HM_HE_H$ stored at 4°C for 0 day had the lowest values of gumminess. Chewiness values of all cakes stored at 4°C were between 113.06-284.09 g_f. $S_LB_HM_HE_L$ stored at 4°C for 18 days had the highest values of chewiness. But $S_LB_HM_HE_H$ stored at 4°C for 0 day had the lowest values of chewiness.

Resilience values of all cakes stored at 4°C were between 0.09-0.24. $S_LB_LM_LE_L$ stored at 4°C for 0 day had the highest values of resilience. But $S_LB_HM_HE_H$ stored at 4°C for 18 days and $S_LB_HM_HE_L$ stored at 4°C for 12 and 18 days had the lowest values of resilience.

The result revealed that when the shelf life increased, the values of hardness, gumminess and chewiness of all cakes in each group stored at 25°C increased significantly ($p \leq 0.05$), but the values of springiness, cohesiveness and resilience of all cakes stored at 25°C decreased significantly ($p \leq 0.05$). Cake made with high ratio of butter, margarine and eggs showed low value of hardness, gumminess and chewiness which was due to the functional of butter and margarine are to envelope the air cells while mixing the ingredients, to enrich protein particles and starches to disperse well in the batter, resulting in a soft texture and moist cake crumb (Pyler, 1988). Proteins in eggs also formed protein network and incorporated the air cells inside the batter, which help produce smooth batters and contribute to volume and texture (Conforti, 2006). Moreover, the result agreed well with Gómez et al. (2007) in that the hardness, gumminess and chewiness of cakes increased but springiness, cohesiveness and resilience of yellow layer cakes decreased during 2 days of storage at 25°C. These findings indicated that both of storage time and temperature influenced the staling rate of the cake especially at lower temperature. The changes of texture properties were the result of retrogradation, the aggregation of polysaccharide chain which may form crystal phases within and outside the starch granules. During storage, some of water migrated from amorphous to crystalline starch, where it was more tightly bound, resulting in an increase of overall firmness and hardness (Schiraldi and Fessas, 2001).

Table 4.21 Texture properties of representative butter cakes from each group stored at 25°C for 6 days

Butter cake	Time (days)	Hardness (g_f)	Springiness (-)	Cohesiveness (-)	Gumminess (g_f)	Chewiness (g_f)	Resilience (-)
$S_LB_HM_HE_H$	0	294.49 ± 18.33^{i}	0.74 ± 0.01^{de}	0.45 ± 0.02^{bc}	139.39 ± 3.55^{g}	113.43 ± 2.51^{f}	0.19 ± 0.01^{c}
	2	309.61 ± 13.79^{i}	0.71 ± 0.01^{fg}	0.33 ± 0.06^{e}	144.56 ± 3.06^{g}	116.65 ± 2.32^{f}	0.16 ± 0.02^{ef}
	4	343.75 ± 22.72^{h}	0.67 ± 0.02^{h}	0.29 ± 0.01^{ef}	145.15 ± 2.23^{g}	119.47 ± 0.68^{f}	0.14 ± 0.01^{hi}
	6	343.64 ± 21.04^{h}	0.65 ± 0.01^{h}	0.27 ± 0.03^{f}	150.28 ± 1.62^{g}	121.20 ± 0.98^{if}	0.13 ± 0.01^{i}
$S_LB_HM_HE_L$	0	680.62 ± 6.74^{b}	0.71 ± 0.01^{gh}	0.46 ± 0.03^{bc}	321.22 ± 4.15^{b}	223.72 ± 4.33^{c}	0.17 ± 0.01^{d}
	2	692.57 ± 9.28^{b}	0.69 ± 0.01^{g}	0.43 ± 0.04^{cd}	337.05 ± 5.59^{b}	225.45 ± 5.61^{c}	0.16 ± 0.01^{ef}
	4	715.81 ± 4.05^{a}	0.65 ± 0.01^{h}	0.40 ± 0.02^{d}	331.41 ± 5.66^{b}	269.53 ± 5.68^{a}	0.15 ± 0.01^{gh}
	6	713.60 ± 8.21^{a}	0.62 ± 0.01^{i}	0.39 ± 0.02^{d}	354.84 ± 2.90^{a}	273.93 ± 3.56^{a}	0.15 ± 0.01^{gh}

Note: Mean values with different letters in each column were significantly different ($p \leq 0.05$) as determined by Duncan's new multiple range test (DMRT), and mean values±SD.

Ref. code: 25615409300216VXU

Table 4.21 Texture properties of representative butter cakes from each group stored at 25^{o}C for 6 days (cont.)

Butter cake	Time (days)	Hardness (g_f)	Springiness (-)	Cohesiveness (-)	Gumminess (g_f)	Chewiness (g_f)	Resilience (-)
$S_LB_LM_HE_H$	0	458.97 ± 2.66^{f}	0.88 ± 0.03^{a}	0.55 ± 0.04^{a}	272.08 ± 2.45^{d}	228.21 ± 6.03^{bc}	0.22 ± 0.01^{b}
	2	486.31 ± 8.82^{e}	0.82 ± 0.01^{b}	0.46 ± 0.01^{bc}	279.61 ± 8.39^{d}	228.24 ± 2.86^{bc}	0.20 ± 0.01^{c}
	4	542.91 ± 11.83^{d}	0.82 ± 0.02^{b}	0.45 ± 0.01^{bc}	281.70 ± 0.91^{d}	229.76 ± 2.07^{bc}	0.19 ± 0.01^{c}
	6	580.27 ± 3.67^{c}	0.77 ± 0.03^{cd}	0.42 ± 0.03^{cd}	300.30 ± 6.00^{c}	236.41 ± 3.60^{b}	0.17 ± 0.01^{d}
$S_LB_LM_LE_L$	0	388.73 ± 2.25^{g}	0.83 ± 0.01^{b}	0.56 ± 0.01^{a}	222.38 ± 3.51^{f}	182.49 ± 4.33^{e}	0.25 ± 0.01^{a}
	2	393.04 ± 5.94^{g}	0.79 ± 0.01^{c}	0.54 ± 0.02^{a}	228.19 ± 6.12^{f}	185.41 ± 8.37^{e}	0.24 ± 0.01^{a}
	4	464.23 ± 5.01^{f}	0.77 ± 0.01^{cd}	0.49 ± 0.01^{b}	235.67 ± 4.38^{ef}	199.52 ± 9.57^{d}	0.22 ± 0.01^{b}
	6	478.82 ± 19.25^{ef}	0.73 ± 0.01^{ef}	0.47 ± 0.01^{bc}	249.32 ± 1.57^{e}	198.68 ± 2.27^{d}	0.21 ± 0.01^{b}

Note: Mean values with different letters in each column were significantly different ($p \leq 0.05$) as determined by Duncan's new multiple range test (DMRT), and mean values$\pm$SD.

Ref. code: 25615409300216VXU

Table 4.22 Texture properties of representative butter cakes from each group stored at 4°C for 18 days

Butter cake	Time (days)	Hardness (g_f)	Springiness (-)	Cohesiveness (-)	Gumminess (g_f)	Chewiness (g_f)	Resilience (-)
$S_LB_HM_HE_H$	0	308.87 ± 2.10^{k}	0.74 ± 0.01^{de}	0.46 ± 0.02^{bc}	143.80 ± 3.55^{l}	113.06 ± 2.51^{m}	0.17 ± 0.01^{d}
	6	438.83 ± 14.55^{ef}	0.67 ± 0.01^{gh}	0.40 ± 0.06^{e}	175.88 ± 3.06^{k}	135.38 ± 2.32^{l}	0.17 ± 0.02^{d}
	12	526.81 ± 12.00^{f}	0.58 ± 0.02^{i}	0.31 ± 0.01^{h}	185.89 ± 2.23^{k}	143.96 ± 0.68^{k}	0.13 ± 0.01^{e}
	18	551.38 ± 13.28^{e}	0.56 ± 0.01^{i}	0.21 ± 0.03^{i}	219.82 ± 1.62^{j}	174.36 ± 0.98^{j}	0.09 ± 0.01^{g}
$S_LB_HM_HE_L$	0	703.64 ± 12.04^{c}	0.71 ± 0.03^{efg}	0.46 ± 0.02^{bc}	317.21 ± 4.64^{d}	223.12 ± 9.75^{f}	0.16 ± 0.01^{d}
	6	719.73 ± 28.14^{c}	0.65 ± 0.04^{h}	0.46 ± 0.02^{bc}	335.63 ± 7.44^{c}	235.77 ± 3.27^{de}	0.14 ± 0.01^{e}
	12	811.35 ± 14.67^{b}	0.58 ± 0.02^{i}	0.38 ± 0.01^{f}	368.03 ± 5.13^{b}	263.60 ± 5.78^{b}	0.10 ± 0.01^{g}
	18	964.46 ± 25.68^{a}	0.57 ± 0.03^{i}	0.35 ± 0.01^{g}	387.99 ± 6.52^{a}	284.09 ± 2.44^{a}	0.10 ± 0.01^{g}

Note: Mean values with different letters in each column were significantly different ($p \leq 0.05$) as determined by Duncan's new multiple range test (DMRT), and mean values±SD.

Ref. code: 25615409300216VXU

Table 4.22 Texture properties of representative butter cakes from each group stored at 4^{o}C for 18 days (cont.)

Butter cake	Time (days)	Hardness (g_f)	Springiness (-)	Cohesiveness (-)	Gumminess (g_f)	Chewiness (g_f)	Resilience (-)
$S_LB_LM_HE_H$	0	462.86 ± 5.29^{hi}	0.86 ± 0.01^{a}	0.55 ± 0.01^{a}	271.26 ± 8.32^{g}	232.93 ± 4.06^{e}	0.22 ± 0.01^{b}
	6	484.63 ± 5.62^{gh}	0.79 ± 0.01^{bc}	0.44 ± 0.02^{d}	282.80 ± 0.49^{f}	235.94 ± 4.73^{de}	0.17 ± 0.01^{c}
	12	622.02 ± 13.17^{d}	0.76 ± 0.02^{cd}	0.36 ± 0.01^{g}	287.61 ± 2.32^{ef}	242.12 ± 2.56^{d}	0.14 ± 0.01^{d}
	18	714.08 ± 12.16^{c}	0.72 ± 0.01^{defg}	0.32 ± 0.01^{h}	296.68 ± 4.88^{e}	253.70 ± 4.62^{c}	0.13 ± 0.01^{e}
$S_LB_LM_LE_L$	0	389.46 ± 0.70^{j}	0.82 ± 0.01^{ab}	0.57 ± 0.01^{a}	223.36 ± 6.76^{j}	185.90 ± 1.29^{i}	0.24 ± 0.01^{a}
	6	446.79 ± 1.53^{i}	0.73 ± 0.01^{def}	0.50 ± 0.01^{b}	238.30 ± 1.71^{i}	197.74 ± 0.99^{h}	0.14 ± 0.01^{d}
	12	489.85 ± 2.36^{g}	0.71 ± 0.01^{efg}	0.44 ± 0.01^{d}	239.67 ± 3.34^{hi}	201.70 ± 6.46^{gh}	0.12 ± 0.01^{f}
	18	500.49 ± 7.06^{g}	0.69 ± 0.01^{fgh}	0.41 ± 0.01^{e}	250.71 ± 0.56^{h}	206.49 ± 6.79^{ag}	0.10 ± 0.01^{g}

Note: Mean values with different letters in each column were significantly different ($p \leq 0.05$) as determined by Duncan's new multiple range test (DMRT), and mean values±SD.

Ref. code: 25615409300216VXU

Figure 4.18 and 4.19 illustrated the relationship between hardness value of cake and storage time at 25°C and 4°C, respectively. $S_LB_HM_HE_L$ showed higher hardness value than the other cake groups for storage at both 25°C and 4°C but storage at 4°C showed much higher increase in hardness with storage time than at 25°C. $S_LB_LM_HE_H$ stored at 25°C and 4°C showed the highest rate of increase in hardness during 6 and 18 days, respectively. But $S_LB_HM_HE_H$ stored at 25°C showed the least rate of increase in hardness during 6 days and $S_LB_LM_LE_L$ stored at 4°C showed the least rate of increase in hardness during 18 days.

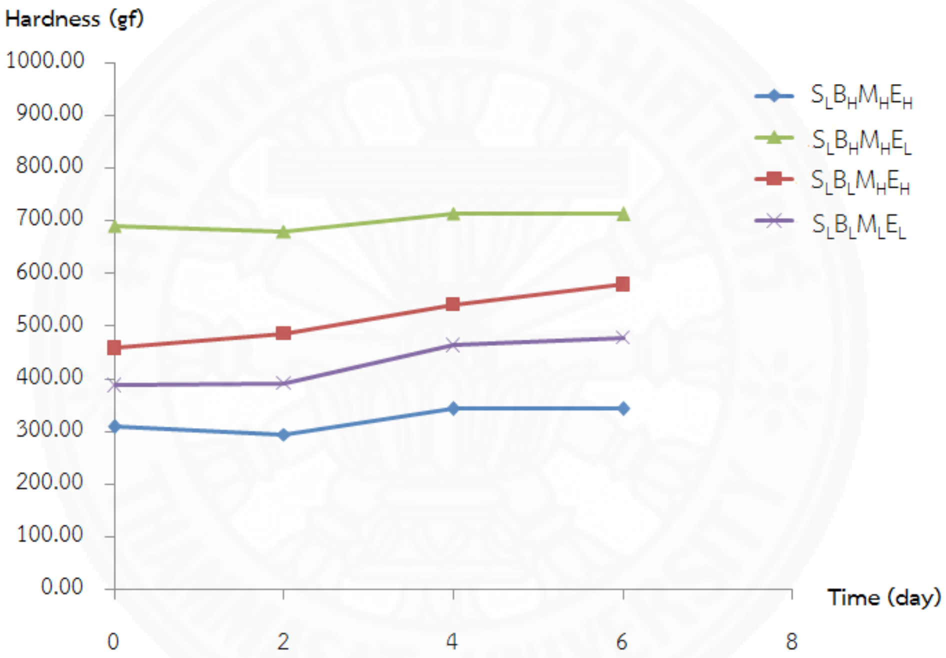

Figure 4.18 The hardness value of representative butter cakes from each group stored at 25°C for 6 days

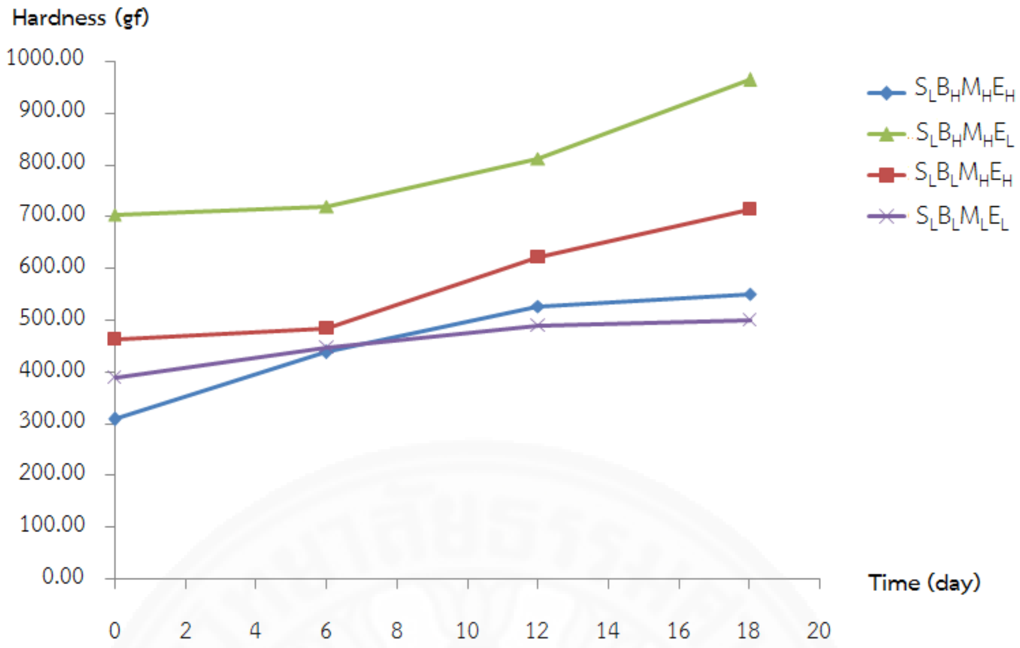

Figure 4.19 The hardness value of representative butter cakes from each group stored at 4°C for 18 days

Table 4.23 and 4.24 showed the retrogradation rate and differential scanning calorimeters (DSC) data of representative butter cakes from each group stored at 25°C for 6 days and 4°C for 18 days, respectively. From Table 4.23, the values of retrogradation rate and enthalpy were significantly difference ($p \leq 0.05$). But T_0, T_p and T_e were not significantly difference ($p>0.05$). Retrogradation rate values of all cakes stored at 25°C were between 0.00-1.00. In each group of cakes, cakes stored for 6 days had the highest values of retrogradation rate. Enthalpy values of all cakes stored at 25°C were between 2.25-6.42 J/g. $S_LB_HM_HE_L$ stored at 25°C for 6 days had the highest values of enthalpy. But $S_LB_LM_LE_L$ stored at 25°C for 0 day had the lowest values of enthalpy.

From Table 4.24, the values of retrogradation rate, enthalpy, onset temperature (T_o) and peak temperature (T_p) were significantly difference ($p \leq 0.05$). But endset temperature (T_e) were not significantly difference ($p>0.05$). Retrogradation rate values of all cakes stored at 4°C were between 0.00-1.00. In each group of cakes, cakes stored for 18 days had the highest values of retrogradation rate. Enthalpy values of all cakes stored at 4°C were between 2.46-6.53 J/g. $S_LB_HM_HE_L$ stored at 4°C for 18 days had the highest values of enthalpy. But $S_LB_LM_LE_L$ stored at 4°C for 0 day had the lowest values of enthalpy. T_0 values of all cakes stored at 4°C were between 29.24-38.48°C. $S_LB_LM_HE_H$ stored at 4°C for 0 day had the highest values of T_0. But all cakes excepted $S_LB_LM_HE_H$ stored at 4°C for 0 day and $S_LB_HM_HE_L$ stored at 4°C for 12 days had the lowest values of T_0. T_p values of all cakes stored at 4°C were between 34.26-43.45°C. $S_LB_LM_LE_L$ stored at 4°C for 0 day had the lowest values of T_p. But $S_LB_HM_HE_H$ stored at 4°C for 0 day, $S_LB_HM_HE_L$ and $S_LB_LM_HE_H$ stored at 4°C for 0-18 days had the highest values of T_p.

The result revealed that when the storage time increased, the retrogradation rate and enthalpy of cakes from each group stored at both 25°C and 4°C significantly increased ($p \leq 0.05$). The result was in agreement with Hesso et al (2015a), the reorganization of amylose into the β-type polymorphic structure depended on the storage temperature in that the enthalpy of the cake stored for 17 days at 20°C was higher than the fresh cake at room temperature. These findings were also agreed well with Ji et al. (2007) in that enthalpy, T_0, T_p and T_c of MiGao cakes increased with 5 days of storage time at 25°C. Starch retrogradation, namely amylopectin retrogradation, is one of the most important factors responsible for bakery staling and it was thought to contribute to crumb firmness. Moreover, cake firming is driven not only by starch retrogradation, but also by other important interactions due to other cake ingredients (eggs, oil/ lipids and sugar) (Hesso et al, 2015c). For this experiment, cake made of high ratio of butter and margarine, stored at 25°C and 4°C, showed high value of enthalpy and T_p. T_p is a peak temperature of the melting of retrogradated amylopectin (Ji et al., 2007). Cake made of high ratio of fat, formed structure of amylose-lipid complexes, used high thermal energy to destroy the bonding of structure (Hesso et al, 2015c).

Table 4.23 Retrogradation rate and differential scanning calorimeters data of representative butter cakes from each group stored at 25°C for 6 days

Butter cake	Time (days)	Retrogadation rate	Enthalpy (J/g)	T_o (°C) [ns]	T_p (°C) [ns]	T_e (°C) [ns]
$S_LB_HM_HE_H$	0	0.00 ± 0.00[g]	2.84 ± 0.05[hi]	31.10 ± 0.37	37.59 ± 0.23	48.72 ± 5.42
	2	0.19 ± 0.01[f]	3.34 ± 0.01[fg]	31.30 ± 0.33	40.59 ± 0.42	53.04 ± 1.65
	4	0.25 ± 0.01[ef]	3.48 ± 0.07[ef]	33.42 ± 0.20	40.84 ± 0.80	53.55 ± 2.11
	6	1.00 ± 0.00[a]	5.41 ± 0.34[b]	32.33 ± 0.23	40.33 ± 0.23	54.83 ± 1.17
$S_LB_HM_HE_L$	0	0.00 ± 0.00[g]	4.25 ± 0.13[d]	31.03 ± 0.13	37.41 ± 0.04	45.20 ± 0.71
	2	0.21 ± 0.10[f]	4.70 ± 0.85[c]	27.10 ± 0.46	40.93 ± 0.69	47.12 ± 0.71
	4	0.55 ± 0.10[c]	5.45 ± 0.33[b]	33.17 ± 0.33	42.08 ± 0.34	51.79 ± 0.23
	6	1.00 ± 0.00[a]	6.42 ± 0.11[a]	31.74 ± 0.31	40.58 ± 0.39	51.83 ± 0.94

Note: Mean values with different letters in each column were significantly different ($p \leq 0.05$) as determined by Duncan's new multiple range test (DMRT), and mean values±SD.

[ns] not significantly different ($p > 0.05$)

T_o = onset temperature (°C), T_p = peak temperature (°C) and T_e = endset temperature (°C)

Ref. code: 25615409300216VXU

Table 4.23 Retrogradation rate and differential scanning calorimeters data of representative butter cakes from each group stored at 25°C for 6 days (cont.)

Butter cake	Time (days)	Retrogadation rate	Enthalpy (J/g)	T_o ($^{\circ}$C) ^{ns}	T_p ($^{\circ}$C) ^{ns}	T_e ($^{\circ}$C) ^{ns}
$S_LB_LM_HE_H$	0	0.00 ± 0.00^{g}	2.69 ± 0.12^{i}	31.71 ± 0.12	42.94 ± 0.22	49.24 ± 0.25
	2	0.35 ± 0.02^{d}	3.41 ± 0.05^{efg}	30.31 ± 1.46	43.60 ± 0.97	83.89 ± 0.71
	4	0.79 ± 0.01^{b}	4.32 ± 0.02^{d}	31.59 ± 0.02	43.51 ± 0.26	52.48 ± 0.59
	6	1.00 ± 0.00^{a}	4.76 ± 0.03^{c}	30.85 ± 0.03	43.08 ± 0.10	51.29 ± 0.47
$S_LB_LM_LE_L$	0	0.00 ± 0.00^{g}	2.25 ± 0.15^{j}	31.04 ± 0.43	37.76 ± 0.01	46.51 ± 0.36
	2	0.32 ± 0.01^{de}	2.71 ± 0.06^{i}	33.85 ± 0.06	36.93 ± 0.71	49.50 ± 0.47
	4	0.62 ± 0.07^{c}	3.13 ± 0.04^{gh}	32.36 ± 0.04	41.00 ± 0.25	48.52 ± 0.35
	6	1.00 ± 0.00^{a}	3.70 ± 0.20^{e}	29.89 ± 0.20	39.33 ± 0.07	48.45 ± 0.11

Note: Mean values with different letters in each column were significantly different ($p \leq 0.05$) as determined by Duncan's new multiple range test (DMRT), and mean values±SD.

^{ns} not significantly different ($p > 0.05$)

T_o = onset temperature ($^{\circ}$C), T_p = peak temperature ($^{\circ}$C) and T_e = endset temperature ($^{\circ}$C)

Ref. code: 25615409300216VXU

Table 4.24 Retrogradation rate and differential scanning calorimeters data of representative butter cakes from each group stored at 4°C for 18 days

Butter cake	Time (days)	Retrogadation rate	Enthalpy (J/g)	T_o (°C)	T_p (°C)	T_e (°C) ^{ns}
$S_LB_HM_HE_H$	0	0.00 ± 0.00^{f}	2.87 ± 0.04^{f}	31.86 ± 0.16^{c}	40.59 ± 0.71^{abcde}	48.73 ± 0.79
	6	0.51 ± 0.06^{d}	4.17 ± 0.06^{de}	30.15 ± 1.02^{c}	37.91 ± 0.29^{e}	51.00 ± 0.33
	12	0.79 ± 0.08^{b}	4.88 ± 0.08^{c}	30.23 ± 0.22^{c}	39.50 ± 0.66^{bcde}	47.29 ± 1.77
	18	1.00 ± 0.00^{a}	5.42 ± 0.14^{b}	31.66 ± 0.66^{c}	39.41 ± 0.39^{bcde}	47.61 ± 3.45
$S_LB_HM_HE_L$	0	0.00 ± 0.00^{f}	3.15 ± 0.12^{f}	31.06 ± 0.22^{c}	40.75 ± 0.24^{abcde}	46.79 ± 0.50
	6	0.36 ± 0.00^{e}	4.35 ± 0.35^{d}	30.89 ± 0.13^{c}	41.49 ± 0.70^{abcde}	49.15 ± 0.02
	12	0.66 ± 0.02^{c}	5.38 ± 0.16^{b}	35.07 ± 0.78^{b}	40.91 ± 0.24^{abcde}	47.38 ± 0.25
	18	1.00 ± 0.00^{a}	6.53 ± 0.19^{a}	31.61 ± 0.62^{c}	41.16 ± 0.36^{abcde}	47.27 ± 0.82

Note: Mean values with different letters in each column were significantly different ($p \leq 0.05$) as determined by Duncan's new multiple range test (DMRT), and mean values±SD.

^{ns} not significantly different ($p > 0.05$)

T_o = onset temperature (°C), T_p = peak temperature (°C) and T_e = endset temperature (°C)

Ref. code: 25615409300216VXU

Table 4.24 Retrogradation rate and differential scanning calorimeters data of representative butter cakes from each group stored at 4°C for 18 days (cont.)

Butter cake	Time (days)	Retrogadation rate	Enthalpy (J/g)	T_o ($^{\circ}$C)	T_p ($^{\circ}$C)	T_e ($^{\circ}$C) ^{ns}
$S_LB_LM_HE_H$	0	0.00 ± 0.00^{f}	3.16 ± 0.22^{f}	38.48 ± 0.37^{a}	42.08 ± 0.01^{abcd}	48.39 ± 0.12
	6	0.47 ± 0.07^{d}	3.93 ± 0.01^{e}	29.72 ± 0.11^{c}	42.83 ± 0.12^{abc}	49.67 ± 0.57
	12	0.75 ± 0.11^{bc}	4.35 ± 0.02^{d}	31.04 ± 0.59^{c}	43.45 ± 0.45^{a}	48.85 ± 0.59
	18	1.00 ± 0.00^{a}	4.76 ± 0.03^{c}	31.36 ± 0.11^{c}	43.17 ± 0.12^{ab}	50.54 ± 0.30
$S_LB_LM_LE_L$	0	0.00 ± 0.00^{f}	2.46 ± 0.01^{g}	30.73 ± 0.08^{c}	34.26 ± 0.47^{f}	45.46 ± 0.17
	6	0.35 ± 0.02^{e}	3.11 ± 0.13^{f}	29.24 ± 0.18^{c}	38.52 ± 0.10^{de}	46.88 ± 0.24
	12	0.76 ± 0.03^{bc}	3.85 ± 0.14^{e}	29.74 ± 0.67^{c}	39.11 ± 0.71^{cde}	50.66 ± 0.51
	18	1.00 ± 0.00^{a}	4.30 ± 0.28^{d}	30.11 ± 0.26^{c}	38.93 ± 0.94^{cde}	56.37 ± 0.49

Note: Mean values with different letters in each column were significantly different ($p \leq 0.05$) as determined by Duncan's new multiple range test (DMRT), and mean values±SD.

^{ns} not significantly different ($p>0.05$)

T_o = onset temperature ($^{\circ}$C), T_p = peak temperature ($^{\circ}$C) and T_e = endset temperature ($^{\circ}$C)

Ref. code: 25615409300216VXU

Figure 4.20 and 4.21 illustrated the relationship between retrogradation rate of cake and storage time at 25°C and 4°C, respectively. The plot showed that $S_LB_LM_HE_H$ showed the highest increase in retrogradation rate but $S_LB_HM_HE_H$ showed the lowest increase in retrogradation rate at 25°C. It is due to the fact that $S_LB_HM_HE_H$ contained high ratio of margarine, which is a water in oil emulsion used in the bakery products to improve texture, volume, softness, aeration and shelf life (Madsen, 1987). Likewise the retrogradation rate of all butter cake increased with storage time at 4°C (Figure 4.21). $S_LB_HM_HE_H$ showed the highest increase in retrogradation rate whereas $S_LB_HM_HE_L$ showed the lowest increase in retrogradation rate at 4°C.

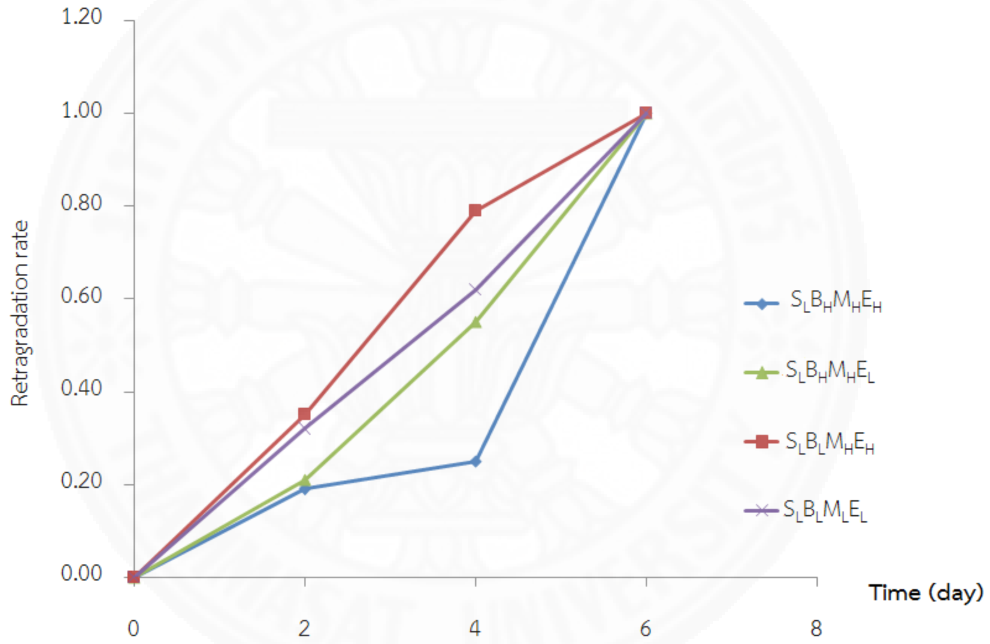

Figure 4.20 The retrogradation rate of representative butter cakes from each group stored at 25°C for 6 days

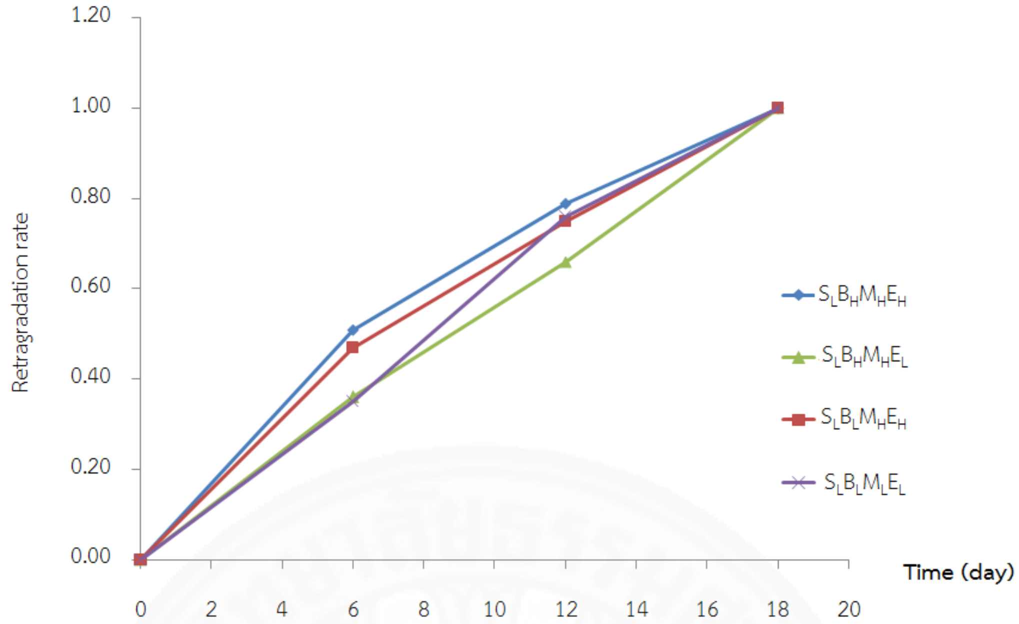

Figure 4.21 The retrogradation rate of representative butter cakes from each group stored at 4°C for 18 days

Table 4.25 and 4.26 showed the sensory evaluation of representative butter cakes from each group stored at 25°C for 6 days and 4°C for 18 days, respectively. From Table 4.25, the liking scores of appearance, crumb color, softness, taste and overall liking were significantly difference ($p \leq 0.05$). The liking score of appearance of all cakes stored at 25°C were between 4.78 and 7.89. $S_LB_LM_HE_H$ stored at 25°C for 0 day had the highest score of appearance. The liking score of crumb color of all cakes stored at 25°C were between 5.28 and 7.52. $S_LB_LM_HE_H$ and $S_LB_LM_LE_L$ stored at 25°C for 0 day had the highest score of crumb color. The liking score of softness of all cakes stored at 25°C were between 5.32 and 7.22. $S_LB_HM_HE_H$, $S_LB_LM_HE_H$ and $S_LB_LM_LE_L$ stored at 25°C for 0 day had the highest score of softness. The liking score of taste of all cakes stored at 25°C were between 5.21 and 7.33. $S_LB_HM_HE_H$ stored at 25°C for 0 day had the highest score of taste. The liking score of overall liking of all cakes stored at 25°C were between 5.31 and 7.32. $S_LB_HM_HE_H$ and $S_LB_LM_HE_H$ stored at 25°C for 0 day had the highest score of overall liking. But $S_LB_HM_HE_L$ stored at 25°C for 6 days had the lowest score of appearance, crumb color, softness, taste and overall liking.

From Table 4.26, the liking scores of appearance, crumb color, softness, taste and overall liking were significantly difference ($p \leq 0.05$). The liking score of appearance of all cakes stored at $4^{\circ}C$ were between 5.31 and 7.83. $S_LB_LM_HE_H$ and $S_LB_LM_LE_L$ stored at $4^{\circ}C$ for 0 day had the highest score of appearance. The liking score of crumb color of all cakes stored at $4^{\circ}C$ were between 5.43 and 7.52. $S_LB_LM_HE_H$ and $S_LB_LM_LE_L$ stored at $4^{\circ}C$ for 0 day, and $S_LB_LM_LE_L$ stored at $4^{\circ}C$ for 6 days had the highest score of crumb color. The liking score of softness of all cakes stored at $4^{\circ}C$ were between 5.63 and 7.27 scores. $S_LB_HM_HE_H$, $S_LB_LM_HE_H$ stored at $4^{\circ}C$ for 0 day and $S_LB_LM_HE_H$ stored at $4^{\circ}C$ for 6 days had the highest score of softness. The liking score of taste of all cakes stored at $4^{\circ}C$ were between 5.89 and 7.35. $S_LB_HM_HE_H$ stored at $4^{\circ}C$ for 0 day had the highest score of taste. The liking score of overall liking of all cakes stored at $4^{\circ}C$ were between 5.59 and 7.38. $S_LB_HM_HE_H$ and $S_LB_LM_HE_H$ stored at $4^{\circ}C$ for 0 day had the highest score of overall liking. But $S_LB_HM_HE_L$ stored at $4^{\circ}C$ for 18 days had the lowest score of appearance, crumb color, softness, taste and overall liking.

The result revealed that when the storage time increased, the liking scores of appearance, crumb color, softness, taste and overall liking of cakes from each group stored at both $25^{\circ}C$ and $4^{\circ}C$ significantly decreased ($p \leq 0.05$). The result agreed well with Inanli et al. (2011) in that the liking score of color, odor, texture and appearance decreased after 6 days of storage time. During storage time, some water migrated from amorphous to crystalline starch, where it was more tightly bound, resulting in an increase of overall crumb firmness and hardness (Schiradi and Fessas, 2001), which caused decreasing the perception of consumer. Moreover, ingredients of cake making had effected on the qualities of cake and perception of consumers during storage. Cake made of low ratio of egg, so the structure of this cake was dense, had high value of texture properties and low in liking scores of all sensory attributes. But cake made of high ratio of margarine and egg which formed a good cake structure and texture had high in liking scores of all sensory attributes, because margarine had a function in entrapping air cells and eggs had a function of incorporating air and emulsification, formed soft cake structure. Moreover, margarine had the role of anti-staling, effected on crumb firmness (Gray and Bemiller, 2003). In addition, according to Gélinas et al. (1999) the incidence of cake staling was reduced during storage when different amounts of the ingredients consisting of different fat type, sugar type, cocoa type, and levels of sodium bicarbonate, flour and egg white were used in combination. In particular, glucose and shortening accelerated the rate of staling. It was concluded that, when these ingredients were used in combination with sucrose and butter, the rate of staling was reduced.

Table 4.27 and 4.28 showed the microbiological properties of representative butter cakes from each group stored at 25°C for 6 days and 4°C for 18 days, respectively. It was found that total bacteria, yeast and mold increased with storage time. Whereas, cakes stored at 4°C were much less than the cake stored at 4°C for all storage time. *Stapphylococcus aureus* and *Bacillus cereus* were not detected in all cake groups all over the storage time either at 25±2°C for 6 days or 4±2°C for 18 days. As referred to the Thai industrial standard of cake (2012) in that the number of total bacteria, yeast and mold, *Stapphylococcus aureus* and *Bacillus cereus* in cake must be less than $1x10^6$, $1x10^2$ CFU/g , less than $1x10^1$ colonies per 1 g, less than $1x10^2$ colonies per 1 g, respectively; therefore, butter cakes from all groups kept at 25°C for 6 days and 4°C for 18 days of storage were conformed with the standards.

Ref. code: 25615409300216VXU

Table 4.25 Sensory evaluation of representative butter cakes from each group stored at 25^{o}C for 6 days

Butter cake	Time (days)	Appearance	Crumb color	Softness	Taste	Overall liking
$S_LB_HM_HE_H$	0	7.67 ± 0.30^{c}	7.28 ± 0.81^{b}	7.22 ± 0.72^{a}	7.33 ± 0.62^{a}	7.32 ± 0.61^{a}
	2	7.54 ± 0.24^{d}	7.23 ± 0.75^{b}	7.02 ± 0.56^{c}	7.18 ± 0.87^{bc}	7.19 ± 0.78^{b}
	4	6.15 ± 0.21^{k}	6.89 ± 0.56^{d}	6.96 ± 0.72^{de}	6.94 ± 0.28^{d}	6.88 ± 0.73^{e}
	6	5.20 ± 0.81^{m}	6.87 ± 0.45^{d}	6.46 ± 0.53^{g}	6.63 ± 0.71^{f}	6.67 ± 0.59^{h}
$S_LB_HM_HE_L$	0	6.22 ± 0.23^{j}	6.29 ± 0.34^{f}	6.17 ± 0.76^{h}	6.28 ± 0.87^{g}	6.43 ± 0.38^{i}
	2	5.98 ± 0.38^{l}	6.19 ± 0.32^{g}	5.98 ± 0.68^{i}	6.11 ± 0.64^{h}	6.11 ± 0.57^{j}
	4	5.18 ± 0.46^{m}	5.62 ± 0.29^{h}	5.68 ± 0.58^{j}	5.78 ± 0.72^{i}	5.88 ± 0.62^{k}
	6	4.78 ± 0.26^{n}	5.28 ± 0.34^{i}	5.32 ± 0.51^{k}	5.21 ± 0.69^{j}	5.31 ± 0.69^{l}

Note: Mean values with different letters in each column were significantly different ($p \leq 0.05$) as determined by Duncan's new multiple range test (DMRT), and mean values$\pm$SD.

Ref. code: 25615409300216VXU

Table 4.25 Sensory evaluation of representative butter cakes from each group stored at 25°C for 6 days (cont.)

Butter cake	Time (days)	Appearance	Crumb color	Softness	Taste	Overall liking
$S_LB_LM_HE_H$	0	7.89 ± 0.63^{a}	7.52 ± 0.51^{a}	7.21 ± 0.47^{a}	7.22 ± 0.42^{b}	7.32 ± 0.45^{a}
	2	7.68 ± 0.56^{c}	7.28 ± 0.27^{b}	7.13 ± 0.72^{b}	7.21 ± 0.57^{b}	7.09 ± 0.73^{c}
	4	7.02 ± 0.72^{g}	6.98 ± 0.53^{c}	6.98 ± 0.71^{cd}	6.82 ± 0.36^{e}	6.99 ± 0.49^{d}
	6	6.89 ± 0.38^{h}	6.74 ± 0.42^{e}	6.69 ± 0.69^{f}	6.79 ± 0.60^{e}	6.72 ± 0.57^{g}
$S_LB_LM_LE_L$	0	7.79 ± 0.59^{b}	7.49 ± 0.65^{a}	7.19 ± 0.49^{a}	7.12 ± 0.71^{c}	7.21 ± 0.66^{b}
	2	7.42 ± 0.65^{e}	7.21 ± 0.76^{b}	7.12 ± 0.66^{b}	7.11 ± 0.52^{c}	7.18 ± 0.77^{b}
	4	7.11 ± 0.38^{f}	7.01 ± 0.38^{c}	6.93 ± 0.84^{e}	6.92 ± 0.64^{d}	6.88 ± 0.65^{f}
	6	6.78 ± 0.48^{i}	6.93 ± 0.37^{cd}	6.42 ± 0.50^{g}	6.56 ± 0.57^{f}	6.82 ± 0.71^{f}

Note: Mean values with different letters in each column were significantly different ($p \leq 0.05$) as determined by Duncan's new multiple range test (DMRT), and mean values±SD.

Ref. code: 25615409300216VXU

Table 4.26 Sensory evaluation of representative butter cakes from each group stored at 4°C for 18 days

Butter cake	Time (days)	Appearance	Crumb color	Softness	Taste	Overall liking
$S_LB_HM_HE_H$	0	7.70 ± 0.32^{b}	7.29 ± 0.39^{c}	7.27 ± 0.71^{a}	7.35 ± 0.63^{a}	7.38 ± 0.72^{a}
	6	7.63 ± 0.27^{c}	7.18 ± 0.46^{d}	7.21 ± 0.63^{b}	7.22 ± 0.57^{b}	7.21 ± 0.63^{de}
	12	7.21 ± 0.34^{e}	7.12 ± 0.27^{e}	7.09 ± 0.52^{c}	7.12 ± 0.46^{c}	7.13 ± 0.58^{ef}
	18	6.92 ± 0.43^{h}	6.79 ± 0.28^{f}	6.77 ± 0.71^{f}	6.98 ± 0.37^{de}	6.89 ± 0.38^{gh}
$S_LB_HM_HE_L$	0	6.21 ± 0.42^{i}	6.22 ± 0.27^{g}	6.19 ± 0.58^{h}	6.25 ± 0.49^{g}	6.49 ± 0.62^{i}
	6	6.08 ± 0.39^{j}	6.12 ± 0.38^{h}	6.12 ± 0.71^{i}	6.27 ± 0.61^{g}	6.28 ± 0.68^{j}
	12	5.78 ± 0.47^{k}	5.98 ± 0.29^{i}	5.89 ± 0.79^{j}	6.11 ± 0.78^{h}	5.95 ± 0.49^{k}
	18	5.31 ± 0.76^{l}	5.43 ± 0.41^{j}	5.63 ± 0.76^{k}	5.89 ± 0.63^{i}	5.59 ± 0.72^{l}

Note: Mean values with different letters in each column were significantly different ($p \leq 0.05$) as determined by Duncan's new multiple range test (DMRT), and mean values±SD.

Ref. code: 25615409300216VXU

Table 4.26 Sensory evaluation of representative butter cakes from each group stored at 4^{o}C for 18 days (cont.)

Butter cake	Time (days)	Appearance	Crumb color	Softness	Taste	Overall liking
$S_LB_LM_HE_H$	0	7.83 ± 0.65^{a}	7.52 ± 0.29^{a}	7.23 ± 0.63^{ab}	7.22 ± 0.29^{b}	7.33 ± 0.62^{ab}
	6	7.73 ± 0.48^{b}	7.43 ± 0.83^{b}	7.22 ± 0.81^{ab}	7.13 ± 0.27^{c}	7.29 ± 0.57^{bc}
	12	7.41 ± 0.36^{d}	7.22 ± 0.62^{d}	6.84 ± 0.66^{e}	6.92 ± 0.47^{e}	7.12 ± 0.59^{f}
	18	7.11 ± 0.72^{f}	7.11 ± 0.51^{e}	6.58 ± 0.62^{g}	6.72 ± 0.36^{f}	6.84 ± 0.70^{gh}
$S_LB_LM_LE_L$	0	7.82 ± 0.58^{a}	7.51 ± 0.41^{a}	7.21 ± 0.58^{b}	7.15 ± 0.72^{bc}	7.25 ± 0.57^{cd}
	6	7.63 ± 0.36^{c}	7.52 ±0.39^{a}	7.09 ± 0.81^{c}	7.12 ± 0.79^{c}	7.14 ± 0.47^{ef}
	12	7.22 ± 0.42^{e}	7.33 ± 0.43^{c}	6.89 ± 0.76^{d}	7.02 ± 0.74^{d}	6.92 ± 0.49^{g}
	18	6.99 ± 0.63^{g}	7.12 ± 0.47^{e}	6.58 ± 0.62^{g}	6.78 ± 0.63^{f}	6.82 ± 0.52^{h}

Note: Mean values with different letters in each column were significantly different ($p \leq 0.05$) as determined by Duncan's new multiple range test (DMRT), and mean values±SD.

Ref. code: 25615409300216VXU

Table 4.27 Microbiological properties of representative butter cakes from each group stored at 25°C for 6 day

Butter cake	Time (days)	Bacteria (CFU/g)	Yeast and mold (CFU/g)	*S.aureus* (CFU/g)	*B.cereus* (CFU/g)
$S_LB_HM_HE_H$	0	<10.0	<10.0	<10.0	<10.0
	2	8.5×10^2	<10.0	<10.0	<10.0
	4	2.7×10^3	1.5×10^1	<10.0	<10.0
	6	1.4×10^5	1.5×10^1	<10.0	<10.0
$S_LB_HM_HE_L$	0	<10.0	<10.0	<10.0	<10.0
	2	2.4×10^2	1.0×10^1	<10.0	<10.0
	4	3.7×10^3	1.5×10^1	<10.0	<10.0
	6	2.8×10^5	2.0×10^1	<10.0	<10.0
$S_LB_LM_HE_H$	0	<10.0	<10.0	<10.0	<10.0
	2	8.4×10^2	<10.0	<10.0	<10.0
	4	4.4×10^4	1.0×10^1	<10.0	<10.0
	6	1.6×10^5	1.0×10^1	<10.0	<10.0
$S_LB_LM_LE_L$	0	<10.0	<10.0	<10.0	<10.0
	2	3.2×10^2	<10.0	<10.0	<10.0
	4	2.7×10^3	1.0×10^1	<10.0	<10.0
	6	2.8×10^4	2.0×10^1	<10.0	<10.0

Ref. code: 25615409300216VXU

Table 4.28 Microbiological properties of representative butter cakes from each group stored at 4°C for 18 day

Butter cake	Time (days)	Bacteria (CFU/g)	Yeast and mold (CFU/g)	*S.aureus* (CFU/g)	*B.cereus* (CFU/g)
$S_LB_HM_HE_H$	0	<10.0	<10.0	<10.0	<10.0
	6	<10.0	$1.0x10^1$	<10.0	<10.0
	12	1.0×10^1	$1.0x10^1$	<10.0	<10.0
	18	1.5×10^1	$1.0x10^1$	<10.0	<10.0
$S_LB_HM_HE_L$	0	<10.0	<10.0	<10.0	<10.0
	6	<10.0	<10.0	<10.0	<10.0
	12	<10.0	<10.0	<10.0	<10.0
	18	$1.5x10^1$	$1.0x10^1$	<10.0	<10.0
$S_LB_LM_HE_H$	0	<10.0	<10.0	<10.0	<10.0
	6	<10.0	<10.0	<10.0	<10.0
	12	<10.0	<10.0	<10.0	<10.0
	18	<10.0	<10.0	<10.0	<10.0
$S_LB_LM_LE_L$	0	<10.0	<10.0	<10.0	<10.0
	6	<10.0	<10.0	<10.0	<10.0
	12	<10.0	$1.0x10^1$	<10.0	<10.0
	18	1.0×10^1	$1.0x10^1$	<10.0	<10.0

Ref. code: 25615409300216VXU

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The clustering analysis result of 12 commercial butter cake products and 27 experimental butter cakes (varied the ratio of 4 ingredients including sugar, butter, margarine and egg) showed 4 groups of butter cakes by their texture properties. Each representative butter cakes from each group had texture properties, microstructure, sensory and properties changed according to storage time and temperature summarized as followed.

Cake made of low ratio of sugar, high ratio of butter, margarine and egg ($S_LB_HM_HE_H$) had texture properties of low values in springiness, cohesiveness, gumminess and chewiness. Microstructure parameters were low in mean cell area, but high values in number of air cell/ unit area. Sensory scores (QDA) were low in hardness and cohesiveness, but high in color intensity, pore size, butter flavor, sweet, salt and after taste (butter).

Cake made of low ratio of sugar and egg, high ratio of butter and margarine ($S_LB_HM_HE_L$) had texture properties of low values in springiness, cohesiveness and resilience but high in gumminess. Microstructures parameters were high in mean cell area, but low in number of air cell/ unit area. Sensory scores (QDA) were low in pore size, hardness and cohesiveness, but high in color intensity, butter flavor, sweet, salt and after taste (butter).

Cake made of low ratio of sugar and butter, high ratio of margarine and egg ($S_LB_LM_HE_H$) had texture properties of high values in springiness, cohesiveness, gumminess and chewiness but low in resilience. Microstructures parameters were low in mean cell area, but high in number of air cell/ unit area. Sensory scores (QDA) were low in sweet, salt and after taste (butter), high in color intensity, hardness and cohesiveness, and moderate in pore size and butter flavor.

Cake made of low ratio of sugar, butter, margarine and egg ($S_LB_LM_LE_L$) had texture properties of high values in springiness, cohesiveness and resilience. Microstructures parameters were low in mean cell area, but high in number of air cell/

Ref. code: 25615409300216VXU

unit area. Sensory scores (QDA) were low in color intensity, butter flavor, sweet, salt and after taste (butter), high in pore size and cohesiveness, and moderate in hardness.

All representative cakes from each group were stored at 25°C for 6 days and 4°C for 18 days. As the storage times for each temperatures increased, texture properties of hardness, gumminess and chewiness increased, but springiness, cohesiveness and resilience decreased. Retrogradation rate, TBA values and enthalpy increased, but a_w decreased. The liking scores of sensory properties; appearance, color, softness, taste, and overall liking decreased. The microbiological properties of all representative cakes from each group, total bacteria, yeast and mold increased. *Stapphylococcus aureus* and *Bacillus cereus* were not detected in all cake groups all over the storage time either at 25°C for 6 days or 4°C for 18 days.

5.2 Recommendations

1) In the study of Texture Profile Analysis (TPA), the probe should be larger than the sample to reduce the shearing force of the sample.

2) For the further study, should keep the cake longer than 18 days at the temperature of 4°C, to study the shelf life of cakes until there would be spoilage by microorganism.

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APPENDICES

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APPENDIX A
Questionnaires

Questionnaire

Studying the storage timeof butter cake

1. Gender ( ) Male 2. Age ( ) 17-21 year ( ) 22-26 years
( ) Female ( ) 27-31 years ( ) over 31 years

2. PLEASE EVALUATE SAMPLE BY RATING ON EACH PRODUCT ATTRIBUTE (9-POINTS HEDONIC SCALE : SCORE 1-9).

1	=	Dislike extremely	4	=	Dislike slightly	7	=	Like moderately
2	=	Dislike very much	5	=	Neither like nor dislike	8	=	Like very much
3	=	Dislike moderately	6	=	Like slightly	9	=	Like extremely

Attributes	Score			
	Sample A	Sample B	Sample C	Sample D
1) Overall appearance				
2) Crumb color				
3) Softness				
4) Taste				
5) Overall liking				

Suggestion

....

....

....

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Questionnaire

Line Scale Test Report Form

Butter cake

Tester name .... Test date ....

HINT: Please test the product from left to right. Then rate the texture sensory properties of the product. Then mark (I) on the line to match the sense in each attribute (1 = lowest intensity of attribute).

<u>Appearance</u>

1. Color intensity

0 15

Low High

2. Pore size

0 15

Low High

<u>Texture</u>

3. Hardness

0 15

Low High

4. Cohesiveness

0 15

Low High

<u>Flavor</u>

5. Butter

0 15

Low High

<u>Taste</u>

6. Sweet

0 15

Low High

7. Salt

0 15

Low High

<u>After taste</u>

8. Butter

0 15

Low High

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APPENDIX B

Differential scanning calorimeters curve

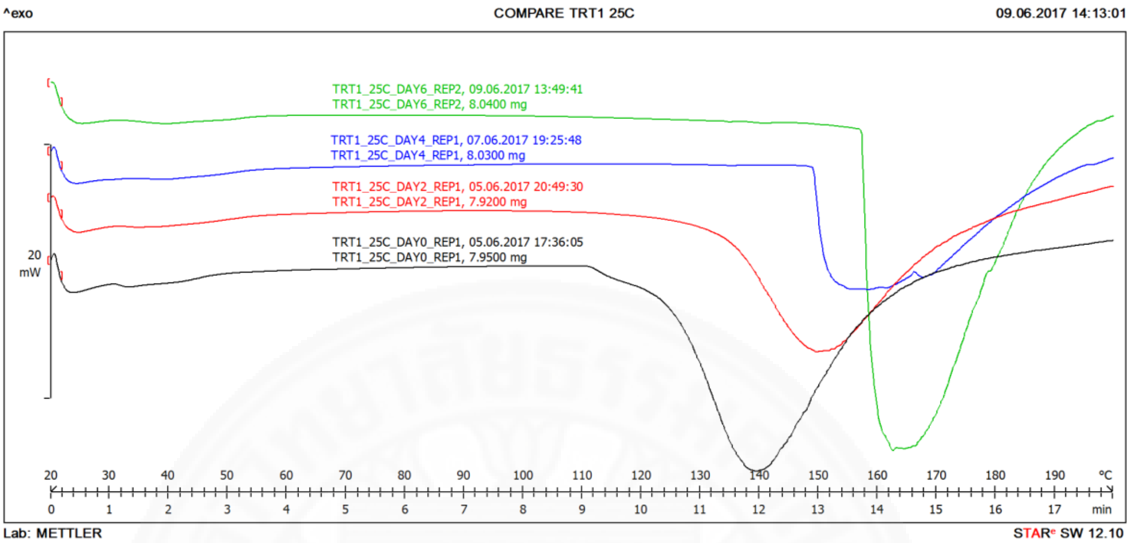

Figure b1 Comparison of differential scanning calorimeters curve of cake group 1 at 25°C

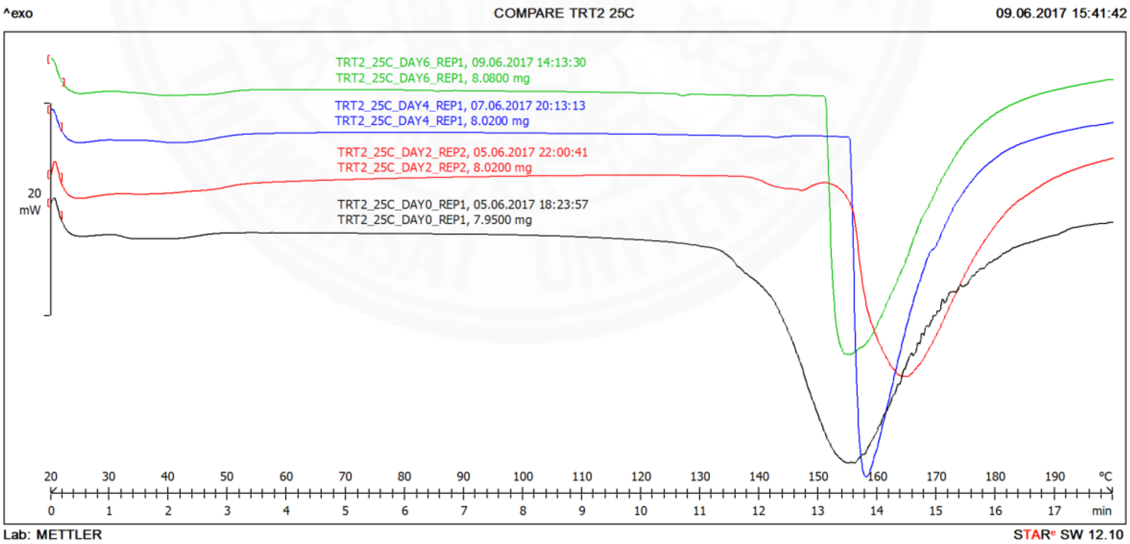

Figure b2 Comparison of differential scanning calorimeters curve of cake group 2 at 25°C

Ref. code: 25615409300216VXU

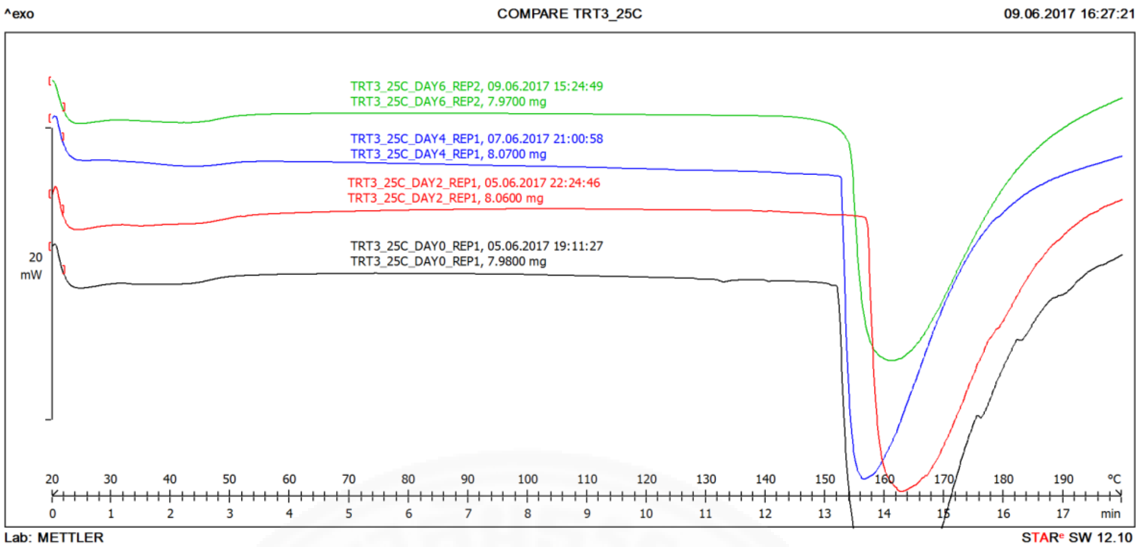

Figure b3 Comparison of differential scanning calorimeters curve of cake group 3 at 25°C

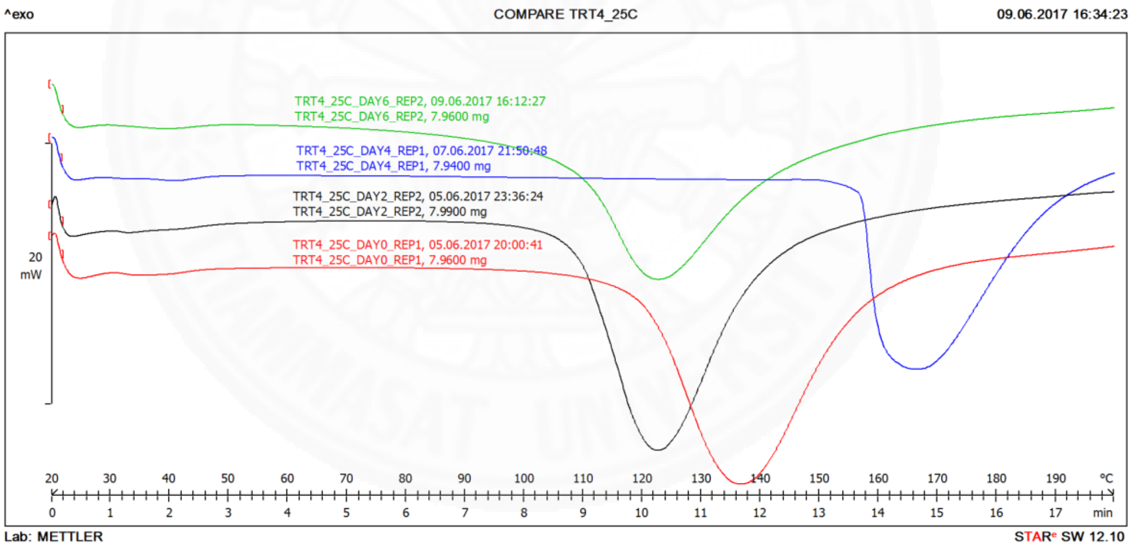

Figure b4 Comparison of differential scanning calorimeters curve of cake group 4 at 25°C

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